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SUPERFUND SITE, TACOMA, WASHINGTON
REMEDIAL INVESTIGATIONS

PB86-104593

DECISIONMAKING FRAMEWORK FOR MANAGEMENT OF DREDGED MATERIAL: APPLICATION TO COMMENCEMENT BAY, WASHINGTON

PREPARED FOR:
WASHINGTON STATE
DEPARTMENT OF ECOLOGY

JULY 1985

PREPARED BY:

US Army Corps
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The State of Washington Department of Ecology has entered into a cooperative agreement with the U.S. Environmental Protection Agency to act as lead agency in the implementation of Phase I Remedial Investigations for the Commencement Bay Nearshore/Tideflats Superfund Site, Washington. Superfund remedial action may involve removing and handling contaminated sediments found in the bay. In addition, ongoing and proposed navigation activities in Commencement Bay require dredging and disposal of contaminated sediments located in the nearshore areas. As a result, Superfund site investigations and planning of navigation projects require identification and evaluation of alternative methods for dredging and disposal of contaminated sediments.

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NOTICE

Throughout the text, tentative decisions by local authorities for the Commencement Bay area are presented. For the Commencement Bay area, the Washington Department of Ecology (WDOE) Superfund Project Manager, other WDOE staff, the Seattle District Corps of Engineers staff, EPA Region X staff, and other local agencies represent involved local authorities.

The tentative decisions are given only for the purpose of presenting concepts on possible methods of quantifying the issues involved for ease of decisionmaking. No consensus has been reached by Commencement Bay area authorities on either the approach or the numerical guidance given, and the workability of the system has not been tested.

The intent of the sections involving local authority tentative decisions, and of the document as a whole, is to provide a valuable first step in arriving at a decisionmaking framework with the full knowledge of the need for further refinement prior to actual implementation.

EXECUTIVE SUMMARY

The State of Washington Department of Ecology (WDOE) has entered into a cooperative agreement with the US Environmental Protection Agency (EPA) to act as lead agency in the implementation of Phase I Remedial Investigations for the Commencement Bay Nearshore/Tideflats Superfund Site, Washington. Superfund remedial action may involve removing and handling contaminated sediments found in the bay. In addition, ongoing and proposed navigation activities in Commencement Bay require dredging and disposal of contaminated sediments located in the nearshore areas. As a result, Superfund site investigations and planning of navigation projects require identification and evaluation of alternative methods for dredging and disposal of contaminated sediments.

By agreement with WDOE, the Seattle District, US Army Corps of Engineers, has requested the Environmental Laboratory, US Army Engineer Waterways Experiment Station (WES), to develop a decisionmaking framework for dredged material management that is based on the results of technically sound test protocols. The decisionmaking framework considers sediment chemistry, physicochemical nature of disposal site environments, and biological effects of sediment contaminants and compares test results from sediments to be dredged with test results from reference sediments and with established criteria. Test protocols are discussed that consider the physicochemical conditions posed by aquatic open-water and confined nearshore and upland disposal environments. Descriptions of the physicochemical conditions at each disposal environment are provided as well as descriptions and citations of the test methods to be conducted. In addition, examples of test results obtained from recent test applications at other Corps dredging projects are discussed. Test results are used to formulate management strategies regarding placement of dredged material in specific physicochemical disposal environments and to determine what treatment and control methods are warranted to dispose of one or more contaminated sediments in an environmentally acceptable manner.

The decisionmaking framework is illustrated by applying it to specific sediments from Commencement Bay in the form of case studies at the end of this report. Since this is the initial development of a decisionmaking framework, a certain amount of refinement will be required to more effectively streamline the approach and quantify the interpretation of test results.

PREFACE

This report presents a decisionmaking framework based on a management strategy for dredged material that incorporates results of a suite of test protocols to assess the effects of physicochemical changes on contaminant mobility from dredged material placed in aquatic, wetland, and upland disposal environments.

This study was conducted at the US Army Engineer Waterways Experiment Station (WES) during the period October 1983 through January 1985 by Drs. C. R. Lee, R. K. Peddicord, and M. R. Palermo, and Mr. N. R. Francinques under the general supervision of Mr. D. L. Robey, Chief, Ecosystem Research and Simulation Division; Mr. A. J. Green, (deceased), formerly Chief, Environmental Engineering Division; and Dr. John Harrison, Chief, Environmental Laboratory.

Technical contributions in the form of examples of test protocol results and preparation of Appendix C tables were received from the following: Dr. B. L. Folsom, Jr., for the plant uptake/bioassay tests; Dr. J. W. Simmers, Dr. S. Kay, and Mr. R. G. Rhett for the earthworm bioassay test; Dr. J. M. Brannon, and Mr. N. R. Francingues for the leachate tests; Dr. M. R. Palermo for the effluent tests; Drs. T. M. Dillon and H. E. Tatem and Mr. V. A. McFarland for the aquatic and benthic bioassay tests; and Mr. J. G. Skogerboe for the surface runoff tests.

Review and constructive comments were received on 17 May 1984 from a working group of that included Dr. R. Chaney, US Department of Agriculture--Agriculture Research Service, Dr. J. Anderson, Battelle Northwest Laboratories; Dr. W. Adams, Monsanto Co.; Mr. N. Rubenstein, US Environmental Protection Agency (EPA), Dr. J. O'Connor, New York University; Dr. W. Peltier, EPA; Dr. W. Pequegnat, Consulant, College Station, Texas; Dr. J. Rogers, North Texas State University; Dr. J. Skelly, Pennsylvania State University; Mr. K. Phillips, Seattle District, US Army Corps of Engineers; and Mr. J. Krull, Washington Department of Ecology.

Additional comments were received on 6-10 August 1984 from members of the WES Plant and Animal Working Groups that included the following: Dr. W. Berry, University of California, Los Angeles; Dr. N. Beyer, US Fish and Wildlife Service; Dr. F. Bingham, University of California, Riverside; Dr. G. Bryan, Marine Biological Society, United Kingdom; Dr. R. Chaney, US Department of Agriculture (USDA); Dr. B. Davies, University College of Wales, United Kingdom;

Dr. C. Edwards, Rothamsted Experimental Station, United Kingdom; Dr. C. Foy, USDA; Dr. Ad H. L. Huiskes, Delta Institute of Hydrobiological Research, The Netherlands; Dr. M. Ireland, University College of Wales, United Kingdom; Dr. M. Johnson, University of Liverpool, United Kingdom; Dr. R. H. D. Lambeck, Delta Institute of Hydrobiological Research, The Netherlands; Dr. J. Marquenie, Technology for Society, TNO, The Netherlands; Dr. E. Neuhauser, Cornell University; Dr. W. Patrick, Jr., Louisiana State University (LSU); Dr. P. Peterson, University of London, United Kingdom; Dr. B. Pierce, Office, Chief of Engineers; Dr. F. Prosi, University of Heidelberg, FRG; Dr. W. Stickle, LSU; Dr. W. van Driel, Institute of Soil Fertility, The Netherlands; Dr. B. Walton, Oak Ridge National Laboratory; Dr. G. Wilhelm, Morton Arboretum; Dr. N. Page, Clemson University; Mr. B. Hunter, University of Essex, United Kingdom; Mr. J. Mansky, New York District; Mr. J. Nieuwenhuize, Delta Institute for Hydrobiological Research, The Netherlands; Mr. A. Palazzo, Cold Regions Research and Engineering Laboratory, CE; Mr. N. Rubenstein, EPA; Ms. N. Houghton, University College of Wales, United Kingdom; and Ms. A. Mudroch, National Water Research Institute, Canada.

The Commanders and Directors of WES during the study and the preparation of this report were COL Tilford C. Creel, CE, and COL Robert C. Lee, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	4046.873	square metres
cubic feet	0.02831685	cubic metres
cubic feet per second	0.02831685	cubic metres per second
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
feet per second	0.3048	metres per second
miles (US statute)	1.609347	kilometres
pounds (mass)	0.4535924	kilograms
square yards	0.8361274	square metres

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DECISIONMAKING FRAMEWORK FOR MANAGEMENT OF DREDGED MATERIAL: APPLICATION TO COMMENCEMENT BAY, WASHINGTON

PART I: INTRODUCTION

Background

1. Navigable waterways of the United States have played a vital role in the Nation's economic growth through the years. The US Army Corps of Engineers (CE), in fulfilling its mission to maintain, improve, and extend these waterways, is responsible for the dredging and disposal of large volumes of sediment each year. Dredging is a process by which sediments are removed from the bottom of streams, rivers, lakes, and coastal waters; transported via ship, barge, or pipeline; and discharged to land or water. Annual quantities of dredged material average about 290 million cu m in maintenance dredging operations and about 78 million cu m in new work dredging operations with the total annual cost now exceeding $250 million.

2. Over 90 percent of the total volume of material dredged is considered acceptable for disposal at a wide range of disposal alternatives. However, the presence of contamination in some locations has generated concern that dredged material disposal may adversely affect water quality and aquatic or terrestrial organisms. Since many of the waterways are located in industrial and urban areas, some sediments may be highly contaminited with wastes from these sources. In addition, sediments may be contaminated with chemicals from agricultural practices.

3. The chemistry of contaminants in sediments, and thus their mobility and potential to adversely impact the environment, is controlled primarily by the physicochemical conditions under which the sediment exists. Fine-grained sediments that are saturated with water typically are anoxic, reduced, and near neutral in pH. These conditions exist in typical open-water aquatic dredged material disposal sites, and may exist in other disposal options such as marsh creation and disposal in shallow water along shorelines. In this document the term "aquatic disposal" is used in a general sense to refer to all disposal conditions in which fine-grained material remains water saturated, anoxic, reduced, and near neutral in pH. In contrast, when a

fine-grained sediment is taken out of the water and allowed to dry, it becomes oxic and the pH may drop considerably. In this document all disposal options in which a fine-grained sediment has these characteristics are referred to generally as "upland disposal," even though such conditions can occur on the surface of dredged material islands, the above-tide portions of fills, etc. Nearshore confined disposal sites could have a combination of anoxic, reduced conditions below tide elevation and oxic conditions in the dredged material placed above tidal elevation.

4. Potential concerns associated with aquatic disposal include contaminants released into the water during and following disposal and the subsequent toxicity and/or bioaccumulation of contaminants by aquatic organisms. Consequences of bioaccumulation may include a wide range of effects from organism toxicity to sublethal genetic abnormalities, food-web biomagnification, and possibly eventual consumption by man. Potential concerns associated with upland disposal include water-quality impacts from effluent discharged during disposal, surface runoff and leachate following disposal, and uptake of contaminants by plants and animals inhabiting the area following disposal operations, with contaminants possibly reaching man by direct or indirect routes. Each of these potential problems can be minimized by one or more management practices.

5. Since the nature and magnitude of contamination in dredged material may vary greatly on a project-to-project basis, the appropriate method of disposal may involve any of several available disposal alternatives. Further, control measures to manage specific problems associated with the presence or mobility of contaminants may be required as a part of any given disposal alternative. An overall management strategy for disposal of dredged material is therefore required. Such a strategy must provide a framework for decisionmaking to select the environmentally preferable disposal alternative and to identify potentially appropriate control measures to minimize problems associated with the presence of contaminants. The decisionmaking framework should also identify and document those sediments that require no special management considerations.

6. The lead responsibility for the development of specific ecological criteria and guideline procedures regulating the discharge of dredged and fill material at the National level was legislatively assigned to the US Environmental Protection Agency (EPA) in consultation or conjunction with the CE.

The enactment of Public Laws 92-532 (the Marine Protection, Research, and Sanctuaries Act of 1972) and 92-500 (the Federal Water Pollution Control Act Amendments of 1972), concerned with the discharge of dredged and fill material, required the CE to participate in developing guidelines and criteria for regulating dredged and fill material disposal. The focal point of research for these procedures is the CE Dredged Material Research Program (DMRP), which was completed in 1978; the ongoing CE Dredging Operations Technical Support (DOTS) Program and the Long-term Effects of Dredging Operations (LEDO) Program; and the ongoing CE/EPA Field Verification Program (FVP). These research programs have provided much of the technical bases for this document.

7. One site in which there is a need to assess the potential environmental impacts of contaminants in sediments is in Commencement Bay in southern Puget Sound near the city of Tacoma, Washington. The State of Washington Department of Ecology (WDOE) has entered into a cooperative agreement with the EPA to act as lead agency in the implementation of Phase I Remedial Investigations for the Commencement Bay Nearshore/Tideflats Superfund Site, Washington. Superfund remedial action may involve removal and handling of contaminated sediments found in the bay. In addition, ongoing and proposed navigation activities in Commencement Bay require dredging and disposal of sediments located in the nearshore areas. As a result, Superfund site investigations and planning of navigation projects require identification and evaluation of alternative methods for dredging and disposal of contaminated sediments.

8. Several studies of the nearshore waters of Commencement Bay have indicated sediment contamination by potentially toxic materials, accumulation of some of those contaminants by estuarine biota, and even possible pollution-related abnormalities in indigenous biota (Tetra Tech 1984). Considerable effort is currently under way to determine the extent of the contamination and the potential threat to public health under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). This effort is necessary to determine what remedial actions are required to clean up and protect the estuarine environment of Commencement Bay.

Purpose and Scope

9. By agreement with WDOE, the Seattle District, CE, has funded the Environmental Laboratory, US Army Engineer Waterways Experiment Station (WES), to develop a decisionmaking framework for environmental assessment of dredged

material based on technically appropriate tests and scientifically sound interpretation of test results. Its major focus is on the question of how should dredged material be tested and the results interpreted to evaluate the degree of potential contaminant impact and the disposal conditions in which the dredged material would have minimal adverse impact on the overall environment. Parts I and II of this document outline the appropriate types of tests and the environmental interpretation of the results. These parts are written so as to be generally applicable to all dredged material evaluations. Part III is an example application of the guidance of Parts I and II to specific Commencement Bay sediments and illustrates the integration of various test results and the role of local regulatory goals and objectives in decisionmaking on the basis of test results. This report describes a framework that provides a means of obtaining a sound technical basis for decisionmaking regarding the disposal of contaminated dredged material. The framework indicates which type of disposal should be considered for a given dredged material and when restrictions on disposal are warranted. Appendices A and B present details of the decisionmaking framework for aquatic and upland disposal options, respectively, and Appendix C contains related information and data tables. Appendix D gives procedures for and examples of mixing-zone calculations.

10. The report describes testing protocols as they are related to the physicochemical conditions posed by aquatic and upland disposal, and in the example of Commencement Bay in Part III, to conditions in a "nearshore" site which will result in some of the material retaining characteristics of aquatic disposal and some of it becoming similar to typical upland conditions. Under each of these alternatives, a discussion is presented of what each test is intended to accomplish and why the information is important. The tests discussed have been proposed in a recent report (Francingues et al. 1985). The present report discusses test procedures and the rationale for when a test should be applied and the interpretation of test results. A decisionmaking framework incorporating the interpretation of test results is discussed and applied to specific sediments from Commencement Bay in case studies.

11. The framework indicates when disposal site controls and treatment options are required and the availability of technology to achieve the required control or treatment. The framework is fully comprehensive as to the present state of the art in technical knowledge, but does not address

economics/cost feasibility of the recommended criteria or public acceptance/ sociopolitical factors. In addition, testing required to address design of a disposal site or selection of necessary control or treatment options is beyond the scope of this report.

PART II: EVALUATION AND MANAGEMENT OF DREDGED MATERIAL DISPOSAL

12. The following discussion presents the general approach to the management of dredged material disposal in reference to a recent document on the subject (Francingues et al. 1985). The discussion becomes more detailed in describing the suite of tests used in the management strategy. The final portion of this part discusses a general decisionmaking framework that incorporates test results and gives guidance on the interpretation of test results for making decisions. The actual application of the framework to specific sediments of Commencement Bay is discussed in Part III of this report.

Management Strategy

13. The following discussion is cited directly from Francingues et al. (1985) and serves as a focus point for this report. The selection of a disposal management strategy must consider the nature of the sediment to be dredged, potential environmental impacts of the disposal of the dredged material, nature and degree of contamination, dredging equipment, project size, site-specific conditions, technical feasibility, economics, and other socioeconomic factors. This discussion presents an approach to consider the nature and degree of contamination, potential environmental impacts, and related technical factors. The approach, shown in the flowchart in Figure 1, consists of the following:

- a. Initial evaluation to assess contamination potential.
- b. Selecting a potential disposal alternative.
- c. Identifying potential problems associated with that alternative.
- d. Testing to evaluate the problems.
- e. Assessing need for disposal restrictions.
- f. Selecting an implementation strategy.
- g. Identifying available control options.
- h. Examining design considerations to evaluate technical and economic feasibility.
- i. Choosing appropriate control measures and technologies.

Initial evaluation

14. The initial screening for contamination is the initial evaluation outlined in the proposed testing requirements for Section 404 of the Clean

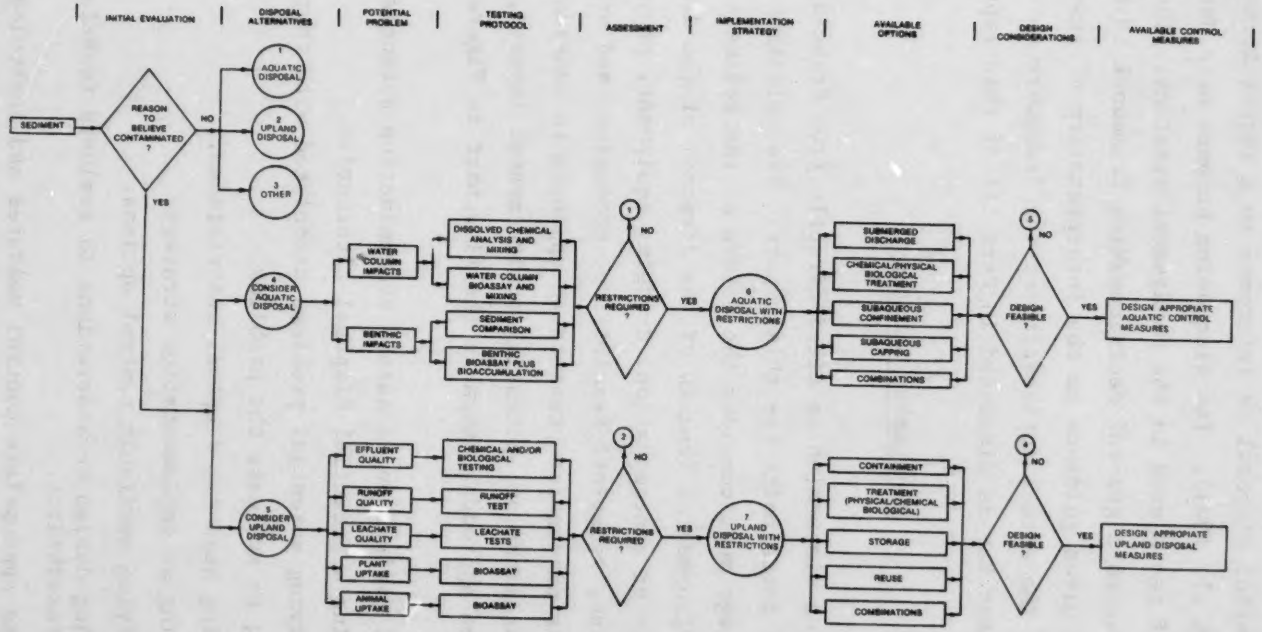
INITIAL EVALUATION
DISPOSAL ALTERNATIVES
POTENTIAL PROBLEM
TESTING PROTOCOL
ASSESSMENT
IMPLEMENTATION STRATEGY
AVAILABLE OPTIONS
DESIGN CONSIDERATIONS
AVAILABLE CONTROL MEASURES
SEDIMENT
REASON TO BELIEVE CONTAMINATED ?
NO
YES
1 AQUATIC DISPOSAL
2 UPLAND DISPOSAL
3 OTHER
4 CONSIDER AQUATIC DISPOSAL
5 CONSIDER UPLAND DISPOSAL
WATER COLUMN IMPACTS
BENTHIC IMPACTS
DISSOLVED CHEMICAL ANALYSIS AND MIXING
WATER COLUMN BIOASSAY AND MIXING
SEDIMENT COMPARISON
BENTHIC BIOASSAY PLUS BIOACCUMULATION
EFFLUENT QUALITY
RUNOFF QUALITY
LEACHATE QUALITY
PLANT UPTAKE
ANIMAL UPTAKE
CHEMICAL AND/OR BIOLOGICAL TESTING
RUNOFF TEST
LEACHATE TESTS
BIOASSAY
BIOASSAY
RESTRICTIONS REQUIRED ?
1
NO
YES
RESTRICTIONS REQUIRED ?
2
NO
YES
6 AQUATIC DISPOSAL WITH RESTRICTIONS
7 UPLAND DISPOSAL WITH RESTRICTIONS
SUBMERGED DISCHARGE
CHEMICAL/PHYSICAL BIOLOGICAL TREATMENT
SUBAQUEOUS CONFINEMENT
SUBAQUEOUS CAPPING
COMBINATIONS
CONTAINMENT
TREATMENT (PHYSICAL/CHEMICAL BIOLOGICAL)
STORAGE
REUSE
COMBINATIONS
DESIGN FEASIBLE ?
5
NO
YES
DESIGN FEASIBLE ?
4
NO
YES
DESIGN APPROPIATE AQUATIC CONTROL MEASURES
DESIGN APPROPIATE UPLAND DISPOSAL MEASURES

Figure 1. Management strategy flowchart

Water Act (EPA 1980). The evaluation is designed to determine if there is reason to believe the sediment contains any contaminants "in forms and amounts that are likely to degrade the aquatic environment, including potential availability to organisms in toxic amounts." This evaluation also allows identification of specific contaminants of concern in the particular sediment in question, so that testing and analyses may be focused on the most pertinent contaminants. The initial evaluation section is quoted as follows from EPA (1980), Section 230.61, page 85362:

> §230.61 Initial evaluation of dredged or filled material.
>
> (a) An initial evaluation shall be conducted and documented to determine if there is reason to believe that any dredged or fill material to be discharged into waters of the United States contains any contaminant above background level. This initial evaluation will be used in assigning the proposed discharge to a category for testing. This evaluation should be accomplished with existing data on file with or readily available to the permitting authority; Regional Administrator, EPA; and other public and private sources, as appropriate. Factors which may be considered for the extraction site and, if appropriate, the disposal site, include, but are not limited to, the following:
>
> (1) Potential routes of introduction of specific contaminants. These may be identified by examining maps, aerial photographs, and other graphic materials that show watercourses, surface relief, proximity to tidal movement, private and public roads, location of buildings, agricultural land, municipal and industrial sewage and storm outfalls, etc., or by making field inspections.
>
> (2) Previous tests on the material at the extraction site or on samples from other similar projects in the vicinity, when there are similarities of sources and types of contaminants, water circulation and stratification, accumulation of sediments, general sediment characteristics, and potential impact on the aquatic environment, as long as no known changes have occurred to render the comparisons inappropriate.
>
> (3) The probability of past substantial introduction of contaminants from land runoff (e.g., pesticides).
>
> (4) Spills of toxic substances or substances designated as hazardous under Section 311 of the Clean Water Act (see 40 CFR Part 116).
>
> (5) Substantial introduction of pollutants from industries.
>
> (6) Source and previous use of materials proposed for discharge as fill.

(7) Substantial natural deposits of minerals and other natural substances.

(b) Before the permitting authority concludes that there is no reason to believe that contaminants are present in the discharge material above background levels, he should consider all relevant, reasonably available information which might indicate its presence. However, if there is no information indicating the likelihood of such contamination, the permitting authority may conclude that contaminants are not present above background levels. Examples of documents and records in which data on contaminants may be obtained are:

(1) Report of Pollution Caused Fish Kills (U.S. EPA)

(2) Selected Chemical Spill Listing (U.S. EPA)

(3) Pollution Incident Reporting System (U.S. CG)

(4) Surface Impoundment Assessment (U.S. EPA)

(5) Identification of In-Place Pollutants and Priorities for Removal (U.S. EPA)

(6) Revised Status Report-Hazardous Waste Sites (U.S. EPA)

(7) Hazardous Waste Management Facilities in the United States--1977 (U.S. EPA)

(8) Corps of Engineers studies of sediment pollution

(9) Sediment tests for previously permitted activities (U.S. CE/District Engineers)

(10) Pesticide Spill Reporting System (U.S. EPA)

(11) STORET (U.S. EPA)

(12) Past 404(b)(1) evaluations

(13) USGS water and sediment data on major tributaries

(14) Pertinent and applicable research reports

(15) NPDES permit records

Contaminant concentrations in the sediment to be dredged can be compared to those concentrations of a reference and/or background sediment to assist in evaluating a sufficient cause for concern. The determination of a critical level of contamination above the reference and/or background should be made on a site-by-site basis and will depend on the administrative goal established for the site such as maintaining nondegradation, achieving cleaner conditions, or returning to background conditions. Under some circumstances contamination factors of 1.5 above reference have been proposed as an acceptable approach. The acceptability of elevation factors must be established through deliberations with appropriate concerned parties and will be a local authority decision.

15. If there is available information indicating contaminants are not present above background levels, restrictions are not required. In this case any disposal alternative may be selected, though the possibility of other environmental impacts such as effects of salinity, substrate alternation, and low dissolved oxygen concentrations must be considered in the final selection. Three disposal alternatives are shown in the flowchart (Figure 1) for uncontaminated or so-called "clean" sediments: [1]* aquatic, [2] upland, and [3] others, which include marsh or wetland development and other beneficial uses. The final selection is based on environmental considerations, available dredging alternatives, site-specific conditions, technical feasibility, economics, and other socioeconomic considerations.

16. If there is reason to believe that contaminants are present, the sediment must be evaluated in relation to the conditions that would be present at the disposal site to examine the potential for environmental impacts. Either aquatic [4] or upland disposal [5] could be initially considered and appropriately evaluated or both alternatives could be evaluated concurrently. The selection of the disposal alternative to be considered is dependent on the potential problems posed by contaminants, available dredging equipment, site-specific conditions, technical feasibility, economics, and socioeconomic considerations. The evaluation of aquatic or upland disposal of contaminated sediment may not necessarily require that additional tests be conducted. As EPA (1980) Section 230.60 points out, "Where the results of prior evaluations, chemical and biological tests, scientific research, and experience can provide information helpful in making a determination, these should be used. Such prior results may make new testing unnecessary."

Consideration of aquatic disposal [4]

17. Consideration of aquatic disposal [4] for a contaminated sediment requires an evaluation of the potential impacts on the water column and the

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* Numbers in brackets refer to the respective disposal alternative as numbered in Figure 1.

benthic environment. Other special disposal problems such as effects on health of disposal personnel would be a rare occurrence but should also be considered. Water column impacts can be evaluated by chemical analysis of dissolved contaminants for which water-quality criteria exist. Bioassays are used when no water-quality criteria exist or when there is concern about possible interactive effects of multiple contaminants. The effects of mixing and dilution should be considered during assessment of the test results.

18. Potential benthic impacts of deposited sediment are first evaluated by comparing both contaminant concentrations and toxicity of the sediments in the dredging and disposal sites. If contaminant concentrations and toxicity in the dredging site sediment are lower than or similar to the concentrations in the disposal site sediment, it can be concluded that disposal will not have further unacceptable adverse impacts on the benthic environment. If contaminant concentrations or toxicity are greater in the dredging site sediment, a bioaccumulation test should be performed. If the initial evaluation for contaminants and initial sediment characterization indicates a potential for special dredging problems (e.g., noxious emissions), appropriate tests must be performed.

19. If the impacts are acceptable, the dredged material can be disposed in aquatic sites without restrictions [1]. If unacceptable, options for aquatic disposal with restrictions [6] must be evaluated.

Aquatic disposal with restrictions [6]

20. Four options are available for implementing aquatic disposal with restrictions [6]. These options include bottom discharge; treating the material by physical, chemical, or biological methods; confining the dredged material subaqueously; and capping the dredged material subaqueously. Each option may be used separately or in combination with other options. The design considerations for these options must be examined to evaluate the technical feasibility of the disposal alternative based on effectiveness, availability, compatibility, cost, and scheduling. If the design is feasible, the appropriate aquatic control measures and technologies can be chosen and implemented. If the design is not feasible, upland disposal [5] should then be considered.

Consideration of upland disposal [5]

21. Consideration of upland disposal [5] for a contaminated sediment requires evaluation of the following potential problems: effluent quality,

surface runoff quality, leachate production and quality, and contaminant uptake by plants and animals. Impacts of effluent, runoff, and leachate quality can be evaluated by chemical analysis of contaminants released in modified elutriate, runoff, and leachate tests, respectively. If the contaminant levels exceed applicable criteria after considering mixing and dilution effects, bioassays are performed to determine the potential toxicity. Plant and animal uptake can be evaluated by appropriate bioassay and bioaccumulation tests. If the initial evaluation and sediment characterization indicates a potential for special dredging or disposal problems (e.g., noxious emissions), appropriate tests must be performed. If the impacts are acceptable, the dredged material can be disposed in upland areas without restrictions [2]. If unacceptable, options for upland disposal with restrictions [7] must be evaluated.

Upland disposal with restrictions [7]

22. Four basic options are available for implementing upland disposal with restrictions. These options include containment, physical/chemical/biological treatment, reuse, and storage and rehandling. Combinations of the options exist for this strategy. The selection of the appropriate option is dependent mainly on the nature and level of contamination, site-specific conditions, economics, and socioeconomic considerations. The design considerations for these options must be examined to evaluate the technical feasibility of the disposal alternative based on effectiveness, availability, compatibility, cost, and scheduling. If the design is feasible, the appropriate upland disposal control measures and technologies can be chosen and implemented. If the design is not feasible, aquatic disposal [4] should be considered.

Description of Test Procedures

Aquatic disposal

Physicochemical conditions

23. When sediments are dredged from a waterway and placed in stable deposits in a low energy aquatic environment, very little change occurs in the physicochemical nature of the dredged material. In other words, when a reduced anaerobic sediment with a pH value near neutral is disturbed, removed, and placed in a similar aquatic environment, it will remain anaerobic with a pH near neutral. Consequently, contaminant mobility at the aquatic disposal

site will be very similar to that occurring at the original dredging site in the waterway. There will be a minor tendency for limited oxidation to occur as the dredged material is mixed with oxygenated water during the dredging operation. However, the oxygen demand of the reduced sediment is usually so great that any oxygen added via the dredging water will be consumed immediately and will not have any important effect on the physicochemical nature of the sediment. The sediment will therefore remain reduced and maintain a near-neutral pH similar to that originally found at the dredging site.

Evaluation of aquatic impacts

24. When highly contaminated dredged material is placed in an aquatic environment, there is a conceptual potential for impacts due to release of contaminants into the water column during disposal, although this potential has rarely been realized in practice. In addition, there is potential for physical effects on benthic organisms and for long-term toxicity and/or bioaccumulation of contaminants from the dredged material. These biological effects are best determined at present by site-specific bioassays. Other special disposal concerns such as potential impacts on health of operating crews would be a rare occurrence and beyond the scope of this document, but should be evaulated when considered appropriate.

Aquatic bioassay and bioaccumulation

25. It must be recognized that aquatic bioassays of dredged material cannot be considered precise predictors of environmental effects in the field. They must be regarded as providing qualitative estimations of those effects, making interpretation of the potential for environmentally adverse effects in the field somewhat subjective. This interpretative uncertainty increases when a parameter whose ecological meaning is uncertain is used as the bioassay end point. In view of the interpretative difficulties, most of the animal bioassays in this document specify death, or occasionally the ecologically important parameters of development or reproduction, as the response to be measured. The term "toxicity" is defined in APHA (1980) as "adverse effect to a test organism caused by pollutants" and is used in this document in a more restricted sense to refer to ecologically important bioassay end points such as those directly related to survival, development, and reproduction.

26. The environmental interpretation of bioaccumulation data is even

more difficult than for bioassays because in many cases it is impossible to quantify either the ecological consequences of a given tissue concentration of a constituent that is bioaccumulated or even the consequences of that body burden to the animal whose tissues contain it. Almost without exception there is little technical basis for establishing, for example, the tissue concentration of zinc in an organism that would be detrimental to that individual, not to mention the uncertainty of estimating the effect of that organism's body burden on a predator. Research is under way at WES, the EPA Environmental Research Laboratory at Narragansett, and other laboratories in the United States and abroad to determine the relationship, if any, between body burden of contaminants and important biological functions. Dillon (1984) provides an initial step in this process, but the database is still inadequate to allow evaluation of the potential ecological consequences of a particular body burden of a specific contaminant(s). Therefore, at present, bioaccumulation data can be interpreted only by comparison to levels in organisms exposed to reference sediment, and to levels determined to be safe for human consumption. Such levels have been established by the US Food and Drug Administration (FDA) and Australian National Health and Medical Research Council for some contaminants in seafood and are presented in Appendix C, Table C1. There are no such levels for aquatic organisms not commonly eaten in these countries. However, there is a potential for contaminants in nonfood organisms to reach some seafood organisms through predation. Although trophic transfer of contaminants from aquatic prey to aquatic predator is known to occur, food-web biomagnification of contaminants to higher concentrations in the predator than in the prey has been established in aquatic systems for only a few contaminants, including polychlorinated biphenyls (PCB), DDT, and mercury (and possibly selenium, zinc, kepone, mirex, benzo(a)pyrene, and naphthalenes) (Biddinger and Gloss 1984, Kay 1984). The above considerations lead to the recommendation that levels in predatory organisms considered safe for human consumption should be applied to aquatic species that are seldom directly consumed by man in order to protect against possible human impacts. The interpretative guidance assumes that any statistically significant bioaccumulation relative to animals not in dredged material, but living in reference material of similar sedimentological character, is potentially undesirable. The evaluation of experimental results using this approach requires the user to recognize the fact that a statistically significant difference cannot be presumed to predict the occurrence of an important impact in the field.

27. Interpretive guidance for environmental tests of dredged material was the subject of a working group convened by the WES on 15-17 May 1984. The participants were all recognized scientific experts in a wide variety of relevant disciplines who also have experience in the practical application of environmental science to regulatory decisionmaking. They included Dr. R. Chaney, US Department of Agriculture--Agriculture Research Service; Dr. J. Anderson, Battelle Northwest Laboratories; Dr. W. Adams, Monsanto Co.; Mr. N. Rubenstein, EPA; Dr. J. O'Connor, New York University; Dr. W. Peltier, EPA; Dr. W. Pequegnat, Consultant, College Station, Texas; Dr. J. Rogers, North Texas State University; Dr. J. Skelly, Pennsylvania State University; Mr. K. Phillips, CE, Seattle District;and Mr. J. Krull, WDOE. After 3 days of discussion, concensus was reached on the following two major points related to regulatory interpretation of properly conducted aquatic bioassay and bioaccumulation testing of dredged material:

a. There is a cause for concern about unacceptable adverse toxicity impacts in the field when laboratory tests result in greater than 50 percent toxicity attributable to the dredged material.

b. Bioaccumulation data can be interpreted in relation to human health, but evaluation of ecological impacts of bioaccumulation is much less certain at present. Tentative assessment of the potential for such impacts must consider concentrations in tissues of reference animals, and other effects of the sediment, such as degree of toxicity.

Water column

28. The standard elutriate (EPA/CE 1977) is appropriate for evaluating the potential for dredged material disposal to impact the water column. Since this test includes contaminants in both the interstitial water and the loosely bound (easily exchangeable) fraction in the sediment, it approximates the fraction of chemical constituents that is potentially available for release to the water column when sediments are dredged and disposed through the water column. The standard elutriate is prepared by mixing the sediment and dredging site water in a volumetric sediment-to-water ratio of 1:4. Mixed with agitation and vigorous aeration for 30 min, it is then allowed to settle for 1 hr. The supernatant is then centrifuged and/or filtered to remove particulates prior to chemical analysis. This procedure is followed because the

water-quality criteria apply only to dissolved contaminants and chemical analyses of an unfiltered water sample cannot identify the bioavailable fraction of sediment-sorbed contaminants. A detailed description of the procedure, including sample preparation, is provided in EPA/CE (1977).

29. Chemical evaluation. Water-column impacts of dredged material may be evaluated either in this paragraph or as specified in paragraph 30, depending on the situation. Where paragraph 14 identifies concern about the presence of specific contaminants that may be released in soluble form, the standard elutriate may be analyzed chemically and the results evaluated by comparison to water-quality criteria for those contaminants after allowance for mixing (paragraphs 31-36) at the disposal site. This provides an indirect evaluation of potential biological impacts of the dissolved contaminants since the water-quality criteria were derived from bioassays of solutions of the various contaminants. Chemical analyses of the standard elutriate are quantitatively interpretable in terms of potential impact only for those contaminants for which specific water quality criteria have been established.

30. Biological evaluation. If the water-quality criteria approach is not taken, the potential for water-column impacts must be evaluated by bioassays, with consideration given to mixing (paragraphs 31-36). An aquatic bioassay should also be used to determine the potential interactions among multiple contaminants. In this way elutriate bioassays can aid in evaluating the importance of dissolved chemical constituents released from the sediment during disposal operations. The standard elutriate is prepared just as for chemical use, but the filtrate is used as a bioassay test solution rather than for chemical analysis. A series of experimental treatments and controls are established using graded dilutions of the elutriate. The test organisms are added to the test chambers and exposed under standard conditions for a prescribed period of time. The surviving organisms are examined at appropriate intervals to determine if the test solution is producing an effect. Any bioassay protocol designed for use with solutions can be used by substituting the standard elutriate for the original solution. A useful general protocol is presented in EPA/CE (1977).

31. Mixing. All data from chemical analyses and bioassays of the standard elutriate must be interpreted in light of mixing. This is necessary since biological effects (which are the basis for water-quality criteria) are a function of biologically available contaminant concentration and exposure

time of the organism. In the field both concentration and time of exposure to a particular concentration change continuously. Since both factors will influence the degree of biological impact, it is necessary to incorporate the mixing expected at the disposal site in the interpretation of both chemical and biological data. *An extremely conservative approach to management of dredged material disposal would be to disregard mixing zone considerations.** This ignores the assimilative capacity of the receiving water. It would frequently result in the application of restrictions on the operation, when, in fact, important impacts would not occur from an unrestricted discharge operation. Disregarding mixing will result in increased cost with little concomitant reduction in potential adverse impacts for most discharge operations.

32. Precise prediction of the shape and areal configuration of the plume within which the required dilution will be achieved is a very difficult problem involving hydrodynamic and sediment transport considerations. Although developmental work is continuing on sophisticated numerical models that will provide this capability, all are expensive because of intensive data input requirements and there is no appropriate verified model that can be suggested for routine use at this time. Consequently, a simplified approach for calculating the projected surface area of the mixing zone is suggested. The approach is based on assuming particular geometrical shapes for the disposal plume depending upon the mode of discharge and the disposal site environment. This approach is explained in Appendix D. In practice it is not necessary to calculate the mixing zone for every contaminant in the discharge, but only the one requiring the greatest dilution. All others will be encompassed within its mixing zone.

33. Use of the simplified approach will indicate the maximum portion (volume) of the total aquatic environment and the surface area projection that would be considered necessary for the proposed discharge activities because it assumes that the dredged material discharge will be completely mixed at the disposal site and that chemical constituents measured in the standard elutriate will behave conservatively following disposal. Included in the discussion in Appendix D are methods for estimating the mixing zone for scow, hopper, and continuous pipeline discharges, as well as for several hydrodynamic conditions in the receiving water.

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* Important sentences are italicized for emphasis.

34. At this time, there is no fully satisfactory simple and rapid technique that can be used to determine the size and configuration or the acceptability of the mixing zone required to accommodate a discharge into an aquatic system. However, there are several important concepts that should be considered in determining the acceptability of a mixing zone. The size of a designated mixing zone should be limited, but each mixing zone should be tailored to a particular receiving water body and no attempt should be made to apply a single size limitation in any water body. In other words, a decision should be based on a case-by-case evaluation at each proposed disposal site and the beneficial use(s) to be protected. In addition to the considerations listed below, a relatively larger mixing zone can be tolerated for intermittent discharges (compared to continuous discharges) without having an important adverse impact on the receiving waters. Concern over acceptability of the calculated mixing zone increases in proportion to:

a. Size

b. Configuration

c. Proportion of volume of receiving water body occupied

d. Proportion of cross-sectional area of receiving water body occupied

e. Time required to achieve desired dilution for each discrete discharge event

f. Frequency of discharges during the dredging and disposal operation

g. Duration of the dredging and disposal operation

h. Proximity to municipal water intakes

i. Proximity to sources of recharge for drinking water aquifers

j. Proximity to areas of high human water-contact activities at the time of major use

k. Proximity to shellfish beds with commercial or recreational importance

l. Proximity to major sport or commercial fishery areas at the time of major use

m. Proximity to unique or concentrated fish or shellfish spawning areas at the time of major use

n. Proximity to unique or concentrated fish or shellfish nursery areas at the time of major use

o. Proximity to major fish or shellfish migration routes at the time of major use

p. Proximity to other major disposal sites or discharges at the time of their use

35. *Commencement Bay area authorities have tentatively decided to determine the acceptability of mixing zones as discussed in paragraph 34 using the following quantitative approach. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph 34 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as implied guidance or a precedent for actual local authority decisions elsewhere about the acceptability of mixing zones.*

a. Acceptability of mixing zone size is entirely case specific and is determined by the following factors.

b. Acceptability of mixing zone configuration is entirely case specific and is determined by the following factors.

c. If *10 percent of less* of the volume of the receiving water body is occupied by the mixing zone, there is cause for *low concern*. If *greater than 10 percent* of the volume of the receiving water body is occupied by the mixing zone, there is cause for *high concern*.

d. If *10 percent or less* of the cross-sectional area of the receiving water body is occupied by the mixing zone, there is cause for *low concern*. If *greater than 10 percent* of the cross-sectional area of the receiving water body is occupied by the mixing zone, there is cause for *high concern*.

e. If the time required to achieve the desired dilution for each discrete discahrge event is *one-half or less* of the interval between discharge events, there is cause for *low concern*. If the time required to achieve the desired dilution for each discrete discharge event is *greater than one-half* the interval between discahrge events, there is cause for *high concern*.

f. If the frequency of discrete discharges is *two or more times* the interval required to achieve the desired dilution, there is cause for *low concern*. If the frequency of discrete discharges is *less than two times* the interval required to achieve the desired dilution, there is cause for *high concern*.

g. If the duration of the dredging and disposal operation is *3 months or less* there is cause for *low concern*. If the duration is *greater than 3 months*, there is cause for *high concern*.

h. If the discharge point is *20 or more times* the mixing zone length from municipal water intakes, there is cause for *low concern*. If the discharge point is *less than 20 times* the mixing zone length from municipal water intakes, there is cause for *high concern*.

i. If the discharge point is *20 or more times* the mixing zone length from sources of recharge for drinking water aquifers, there is cause for *low concern*. If the discharge point is *less than 20 times* the mixing zone length from sources of recharge for drinking water aquifers, there is cause for *high concern*.

j. If the discharge point is *10 or more times* the mixing zone length from areas of high human water-contact activities at the time of major use, there is cause for *low concern*. If the discharge point is *less than 10 times* the mixing zone length from such areas, there is cause for *high concern*.

k. If the discharge point is *10 or more times* the mixing zone length from shellfish beds with commercial or recreational importance, there is cause for *low concern*. If the discharge point is *less than 10 times* the mixing zone length from such areas, there is cause for *high concern*.

l. If the discahrge point is *10 or more times* the mixing zone length from major sport or commercial fishing areas at the time of major use, there is cause for *low concern*. If the discharge point is *less than 10 times* the mixing zone length from such areas, there is cause for *high concern*.

m. If the discharge point is *10 or more times* the mixing zone length from unique or concentrated fish or shellfish spawning areas at the time of major use, there is cause for *low concern*. If the discharge point is *less than 10 times* the mixing zone length away from such areas, there is cause for *high concern*.

n. If the discharge point is *10 or more times* the mixing zone length from unique or concentrated fish or shellfish nursery areas at the time of major use, there is cause for *low concern*. If the discharge point is *less than 10 times* the mixing zone length away from such areas, there is cause for *high concern*.

o. If the discharge point is *5 or more times* the mixing zone length from major fish or shellfish migration routes at the time of major use, there is cause for *low concern*. If the discharge point is *less than 5 times* the mixing zone length away from such areas, there is cause for *high concern*.

p. If the discharge point is *5 or more times* the mixing zone length from other major disposal sites or discharges at the time of their use, there is cause for *low concern*. If the discharge point is less than 5 times the mixing zone length away from such areas, there is cause for *high concern*.

A finding of *high concern* in any five or more factors leads to a DECISION OF UNACCEPTABLE MIXING ZONE. Finding of *high concern* in four or less factors leads to a DECISION OF ACCEPTABLE MIXING ZONE.

36. Several authors have defined mixing zones in terms of biological effects. However, the mixing zone calculated by the method described should not be equated with a zone of adverse biological impact. The basis for the recommended approach is the fact that the effects of a discharge are a function of exposure concentration and exposure time. Although appropriate and applicable water-quality criteria or bioassay results are used to define the volume of water in which acceptable concentrations may be equalled or exceeded, the duration of mixing zone conditions cannot be easily quantified at this time. Therefore, the method should only be used to estimate the volume and surface area at a disposal site within discharge concentrations will exceed a particular value during the actual discharge.

Benthic

37. It is generally felt that if a dredged material is going to have an environmental impact, the greater potential for impact lies with the deposited sediment at the disposal site. This is because it is not mixed and dispersed as rapidly or as greatly as the dissolved material; most contaminants remain associated with the particulates; and bottom-dewlling animals live and feed in and on the deposited material for extended perids. Therefore, the major evaluative efforts should be placed on the deposited material. No chemical procedures exist that will determine the environmental activity of any contaminants or combination of contaminants present in the solid phase of dredged material. Therefore, animals are used in a bioassay to provide a measurement of environmental activity of the chemicals found in the material.

38. Scientific studies conclusively indicate that most subaqueous disposal of dredged material in low-energy aquatic environments where stable mounding will occur will generally minimize changes in mobility of most contaminants (Brannon 1978; Gambrell, Khalid, and Patrick 1978; Neff, Foster, and Slowey 1978; Wright 1977). The potential for accumulation of a contaminant in the tissues of an organism (bioaccumulation) may be affected by exposure concentration and factors such as duration of exposure, salinity, water hardness, temperature, chemcal form of the contaminant, sediment characteristics such as organic carbon content, and the particular organism under study. The relative importance of these factors varies. Elevated concentrations of contaminants

in the ambient medium or associated sediments are not always indicative of high levels of contaminants in tissues of benthic invertebrates or of biological effects.

39. Potential benthic impacts are best evaluated by a combined consideration of total or bulk chemical analyses of the sediment to identify contaminants present and toxicity test(s) to determine their bioavailability. If results of these tests do not provide sufficient information for decisionmaking as discussed later in this document, a bioaccumulation test should be performed to determine the potential for contaminants to accumulate in the tissues of animals exposed to the dredged material.

40. Benthic or deposited sediment bioassays are derived from more traditional techniques for testing contaminants in solution. While there are many variations, those most useful for this document all involve exposure of aquatic test organisms to deposits of whole sediment for a specified period, followed by quantification of the responses. For reasons of regulatory interpretation and implementation, the response of choice here is mortality (and occasionally development or reproduction), as discussed in paragraph 25. A technique widely used and suitable for a wide variety of aquatic macroorganisms is given in EPA/CE (1977). This technique should be utilized to test effects on a finfish, a crustacean, a mollusk, and an annelid acceptable to all local interests as sufficiently sensitive and adequately representative of the local aquatic environment. Many other exposure designs, species, and life stages can also provide useful information and may be utilized in addition to, or instead of, those described in EPA/CE (1977). All widely recognized sediment bioassay techniques of regulatory utility involve toxic effects of exposure of a few days to a few weeks. Tissues of surviving organisms which exceed about 1 g in weight could be analyzed for contaminants at the end of the exposure period to indicate the potential for bioaccumulation from the sediments. The contaminants to be analyzed should be those for which there is a sufficient cause for concern as identified in paragraph 14. In order to best interpret bioaccumulation data, it is necessary to know concentrations in tissues at steady-state rather than only at some intermediate point on the uptake curve. This can be achieved by extending the exposure period until steady-state is reached, although this can raise serious questions about the representativeness of uptake after extended time in the laboratory unless elaborate precautions are taken. Another alternative is to calculate

steady-state tissue concentration based on sequential data collected over a few days and a first-order uptake-depuration kinetics model. This has been shown to give acceptable estimations of steady-state based on a few days exposure by Branson et al. (1975) and McFarland, Gibson, and Meade (1984). A third approach, probably the best under the circumstances where it is possible, is the use of field data as discussed in EPA/CE (1977). There is presently no generally accepted quantitative means of assessing potential long-term changes in sediment effects due to possible breakdown of some organic compounds into compounds of greater of lesser bioavailability and effect.

Upland disposal

Physicochemical conditions

41. When dredged material is placed in an upland environment in which it does not remain water saturated, drastic physicochemical changes occur. As soon as the dredged material is placed in a confinement area and allowed to be exposed to the atmosphere, oxidation processes begin. The influent slurry water initially is dark in color and reduced with little oxygen as it is discharged into the confinement area from a hydraulic dredge. Mechanically dredged sediments such as with a clamshell will have sediment pore water that will initially be dark in color and reduced. As the slurry water passes across the confined disposal site and approaches the discharge weir, the water becomes oxygenated and will usually become light gray or yellowish light brown. The color change indicates further oxidation of iron complexes in the suspended particulates as they move across the confinement. Once disposal operations are completed, dredged material consolidation will continue to force pore water up and out of the dredged material and it will drain toward the discharge weir. This drainage water will continue to become oxidized and lighter in color. Once the surfaced pore water has been removed from the confinement, the surface of the dredged material will become oxidized and lighter in color, such as changing from black to light gray. The dredged material will begin to crack as it dries out. Accumulation of salts will develop on the surface of the dredged material and especially on the edge of the cracks. Rainfall events will tend to dissolve and remove these salt accumulations in surface runoff. Recent research on contaminant mobility from dredged material placed in an upland disposal site indicates that certain metal contaminants can become dissolved in surface runoff as dredged material dries out. During the drying

process, organic complexes become oxidized and decomposed. Sulfide compounds also become oxidized to sulfate salts. These chemical transformations could release complexed contaminants to surface runoff, soil pore water, and leachate through the material. In addition, plants and animals that colonize the upland site could take up and bioaccumulate these released contaminants. Contaminant mobility will be significantly controlled by the physicochemical changes that occur during drying and oxidation of the dredged material.

Contaminant mobility determinations

42. Upland disposal of contaminated dredged material must be planned to contain the dredged material within the site and restrict contaminant mobility out of the site in order to control or minimize potential environmental impacts. There are five possible mechanisms for transport of contaminants from upland disposal sites:

a. Release of contaminants in the effluent during disposal operations.
b. Surface runoff of contaminants in either dissolved or suspended particulate form following disposal.
c. Leaching into ground water and surface waters.
d. Plant uptake directly from sediments, followed by indirect animal uptake from feeding on vegetation.
e. Animal uptake directly from sediments.

The environmental impact of upland disposal of contaminated dredged material may be more severe than aquatic discharge (Gambrell, Khalid, and Patrick 1978; Jones and Lee 1978).

43. Any test protocol used to predict contaminant mobility should account for the physicochemical changes occurring in the dredged material when placed in the specific disposal environment. The following discussion of test protocols will address each of the above aspects in detail.

44. Effluent quality. Water-quality effects of upland disposal effluents (water discharged during active disposal operations) have been identified as one of the greatest deficiencies in knowledge of the environmental impact of dredged material disposal (Jones and Lee 1978). Dredged material placed in an upland disposal area undergoes sedimentation, while clarified supernatant waters are discharged from the site as effluent during active dredging operations. The effluent may contain levels of both dissolved and particulate-associated contaminants. A large portion of the total contaminant level is particulate associated.

45. The standard elutriate test is sometimes used to evalaute effluent water quality, but this test does not reflect the conditions existing in confined disposal sites that influence contaminant release. A modified elutriate test procedure, developed under the CE Long-term Effects of Dredging Operations (LEDO) Research Program (Palermo 1984), can be used to predict both the dissolved and particulate-associated concentrations of contaminants in upland disposal area effluents (water discharged during active disposal operations). The laboratory test simulates contaminant release under upland disposal conditions and reflects sedimentation behavior of dredged material, retention time of the containment, and chemical environment in ponded water during active disposal.

46. The modified elutriate test procedure is illustrated in Figure 2. Sediment and dredging-site water are mixed to a slurry concentration equal to

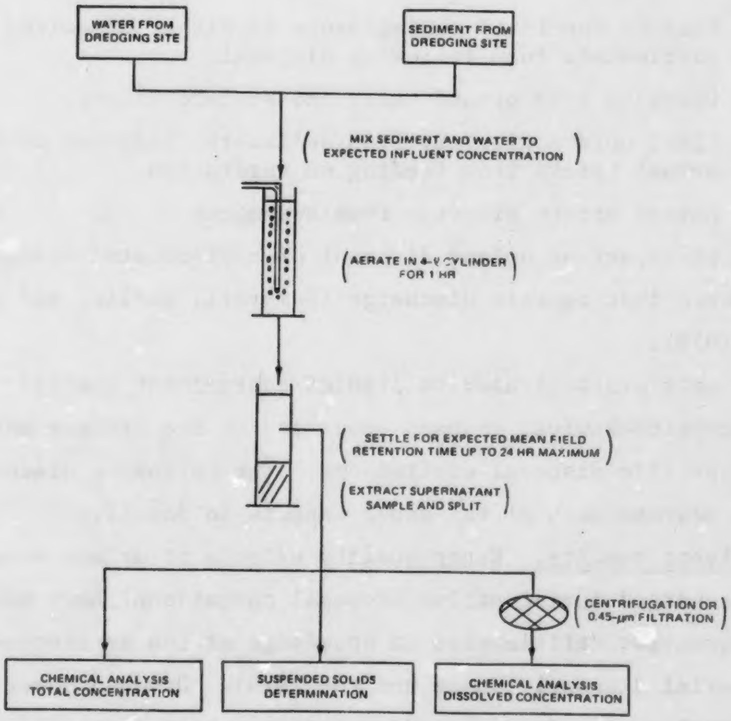
WATER FROM DREDGING SITE
SEDIMENT FROM DREDGING SITE
MIX SEDIMENT AND WATER TO EXPECTED INFLUENT CONCENTRATION
AERATE IN 4-ℓ CYLINDER FOR 1 HR
SETTLE FOR EXPECTED MEAN FIELD RETENTION TIME UP TO 24 HR MAXIMUM
EXTRACT SUPERNATANT SAMPLE AND SPLIT
CENTRIFUGATION OR 0.45-μm FILTRATION
CHEMICAL ANALYSIS TOTAL CONCENTRATION
SUSPENDED SOLIDS DETERMINATION
CHEMICAL ANALYSIS DISSOLVED CONCENTRATION

Figure 2. Modified elutriate test procedure

the expected influent concentration under field conditions. The mixed slurry is aerated in a 4-ℓ cylinder for 1 hr to ensure that oxidizing conditions will be present in the supernatant water. Following aeration, the slurry is allowed to settle under quiescent conditions for a period equal to the expected mean field retention time, up to a maximum of 24 hr. A sample is then extracted from the supernatant water and analyzed for total suspended solids, and dissolved and total concentrations of contaminants of concern as described in paragraph 14. The contaminant fractions of the total suspended solids may then be calculated. Column settling tests, similar to those used for design of disposal areas for effective settling (Palermo, Montgomery, and Poindexter 1978; Palermo 1984), are used to define the concentration of suspended solids in the effluent for a given operational condition, i.e. ponded area, depth, and inflow rate. Using results from both of these analyses, a prediction of the total concentration of contaminants can be made. The predictive technique is illustrated in Figure 3. Detailed procedures are given in Palermo (1984).

47. The acceptability of the proposed upland disposal operation can be evaluated by comparing the predicted dissolved contaminant concentrations with

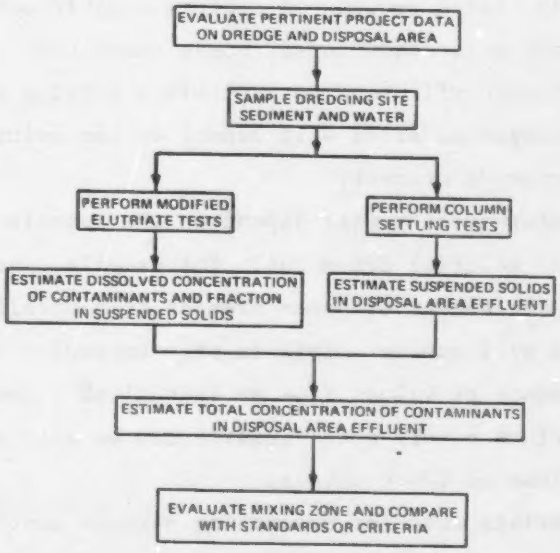
EVALUATE PERTINENT PROJECT DATA ON DREDGE AND DISPOSAL AREA
SAMPLE DREDGING SITE SEDIMENT AND WATER
PERFORM MODIFIED ELUTRIATE TESTS
PERFORM COLUMN SETTLING TESTS
ESTIMATE DISSOLVED CONCENTRATION OF CONTAMINANTS AND FRACTION IN SUSPENDED SOLIDS
ESTIMATE SUSPENDED SOLIDS IN DISPOSAL AREA EFFLUENT
ESTIMATE TOTAL CONCENTRATION OF CONTAMINANTS IN DISPOSAL AREA EFFLUENT
EVALUATE MIXING ZONE AND COMPARE WITH STANDARDS OR CRITERIA

Figure 3. Effluent quality predictive technique

applicable water-quality standards while considering an appropriate mixing zone and the quality of the receiving water body. Where the primary administrative goal is maximum containment of contaminants, appropriate controls and restrictions may be required to first meet water-quality criteria without a mixing zone or, secondarily, to ensure that an acceptable mixing zone is maintained.

48. Surface runoff quality. After dredged material has been placed in an upland disposal site and the dewatering process has been initiated, contaminant mobility in rainfall-induced runoff is considered in the overall environmental impact of the dredged material being placed in a confined disposal site. The quality of the runoff water can vary depending on the physicochemical process and the contaminants present in the dredged material. Drying and oxidation will promote aerobic microbiological activity, which more completely breaks down the organic component of the dredged material and oxidizes sulfide compounds to more soluble sulfate compounds. Concurrently, reduced iron compounds will become oxidized and iron oxides will be formed that can act as metal scavengers to adsorb soluble metals and render them less soluble. The pH of the dredged material will be affected by the amount of acid-forming compounds present as well as the amount of basic compounds that can buffer acid formation. Generally, large amounts of sulfur, organic matter, and/or pyrite material will generate acid conditions. Basic components of dredged material such as calcium carbonate will tend to neutralize acidity produced. The resulting pH of the dredged material will depend on the relative amounts of acid-formed and basic compounds present.

49. Runoff water quality will depend on the results of the above processes as the dredged material dries out. For example, should there be more acid formation than the amount of bases present to neutralize the acid, then the dredged material will become acidic in pH. Excessive amounts of pyrite when oxidized can reduce pH values from an initial pH 7 down to pH 3. Under these conditions surface runoff water quality can be acid and could contain elevated concentrations of trace metals.

50. An appropriate test for evaluating surface runoff water quality must consider the effects of the drying process to adequately estimate and predict runoff water quality. At present there is no single simplified laboratory test to predict runoff water quality. Research was initiated in November 1984 to develop such a test. A laboratory test using a rainfall simulator

has been developed and is being used to predict surface runoff water quality from dredged material as part of the CE/EPA Field Verification Program (FVP) (Lee and Skogerboe 1983a, 1983b; Westerdahl and Skogerboe 1981). This test protocol involves taking a sediment sample from a waterway and placing it in a soil-bed lysimeter in its original wet reduced state. The sediment is allowed to dry out. At intervals during the drying process, rainfall events are applied to the lysimeter, and surface runoff water samples are collected and analyzed for selected water-quality parameters. Rainfall simulations are repeated on the soil-bed lysimeter until the sediment has completely dried out. Results of the tests can be used to predict the surface runoff water quality that can be expected in a confined disposal site when the dredged material dries out. From these results control measures can be formulated to treat surface runoff water if required to minimize the environmental impact to surrounding areas.

51. An example of the use of this test protocol can be cited (Lee and Skogerboe 1983b). An estuarine dredged material highly contaminated with the metals zinc, copper, cadmium, nickel, and chromium was evaluated using this test procedure. An acid rainfall simulating typical rainfall quality at the upland disposal site was used. Test results indicated significant solubilization of these metals in surface runoff water after the dredged material dried out. The pH of the dredged material became acid because of limited base neutralizing compounds present and the acid rainfall applied. The oxidation of sulfide compounds and organic complexes apparently released metals into more soluble and mobile forms. Based on these test results, control measures were designed to neutralize acidity and remove these metals in surface runoff water.

52. Leachate quality. Subsurface drainage from disposal sites in an upland environment may reach adjacent aquifers or may enter surface waters. Fine-grained dredged material tends to form its own disposal area liner as particles settle with percolation drainage water, but the consolidation may require some time for self-sealing to develop. In addition, diffusion of contaminants through fine-grained materials will continue even after the self-sealing has stopped much of the water convection. It is surmised, but not demonstrated, that hydrophobic organic contaminants associate with naturally occurring dissolved organic carbon and thus can diffuse into ground water beneath a site. Further work is needed to substantiate this theory.

Since most contaminants potentially present in dredged material are closely adsorbed to particles, primarily the dissolved fraction will be present in leachates. A potential for leachate impacts exists when a dredged material from a saltwater environment is placed in an upland site adjacent to freshwater aquifers or to surface waters. The site-specific nature of subsurface conditions is the major factor in determining possible impact (Chen et al. 1978).

53. An appropriate leachate quality testing protocol must predict which contaminants may be released in leachate and the relative degree of release. There is presently no routinely applied testing protocol to predict leachate quality from dredged material disposal sites. An evaluation of available leaching procedures is needed before a leaching test protocol for confined dredged material can be recommended. Although a wide variety of leaching or extraction tests have been proposed for hazardous waste (Lowenbach, King, and Cheromisinoff 1977), none have been field verified for use to evaluate leaching of dredged material placed in upland disposal sites.

54. A review of the literature has indicated that theoretical models and data on the leaching potential of dredged material are needed in order to evaluate alternative strategies for the treatment and containment of contaminants in upland disposal sites. Theoretical developments that are needed involve pertinent transport rate equations that describe the leaching of chemicals from dewatered and consolidated dredged material. Data gaps include lack of sufficient information on: (a) bulk transport of contaminants by seepage; (b) contaminant leachability under various environmental conditions; and (c) long-term geochemical consequences that alter contaminant leachability. Leaching tests that can assist in the development of an appropriate predictive protocol for Commencement Bay sediments are being developed at the WES.

55. Development of leachate prediction models using mass transport equations will require information on the relative significance of intraparticle diffusion, surface desorption, film diffusion, and other possible rate-controlling mechanisms for contaminant leaching (e.g., irreversible chemical reactions). Serial batch leach tests (Houle and Long 1980) can indicate whether leaching of a sediment is an equilibrium or kinetically controlled process. Theoretical considerations indicate that, with proper interpretation, results from serial batch leach tests can yield coefficients suitable for modeling contaminant leaching in a confined disposal site. Predicative

techniques, including serial batch leach tests, are presently being evaluated at the WES (Hill, Myers, and Brannon 1985).

56. Column leach tests using specially constructed permeameters can provide information needed for modeling bulk transport of contaminants in an upland disposal site (Goerlitz 1984). The disposal site environment is simulated in a test column by passing a reference liquid or site water through the dredged material. Comparison of batch leach test and column leach test results can indicate the relative significance of bulk transport and diffusive transport within a column of dredged material, and the relative importance of film effects and nonequilibrium processes on contaminant desorption mechanisms. The potential use of column and batch leaching tests for predicting leachate quality in an upland disposal site is presently under investigation at WES. Routine testing procedures cannot be recommended at this time.

57. Long-term geochemical changes influencing leachate quality can only be assessed directly by long-term testing procedures. Use of large pilot-scale leaching columns similar to those described by the Buffalo District (US Army Engineer District, Buffalo 1983) maintained under the environmental conditions that exist in a confined disposal facility will provide such information. This leaching procedure will determine the nature of long-term contaminant releases and the amount of release of each contaminant over time. Information on changes in leachate quality as a function of sediment geochemical alteration under the prevailing environmental conditions will also be provided. From this information, specific treatment of the dredged material and/or placement of an appropriate liner can be formulated and designed into the disposal management strategy. Alternate leaching procedures that address long-term concern are presently under investigation and will be recommended after appropriate testing and verification.

58. Plant uptake. After dredged material has been placed in either an intertidal, wetland, or upland environment, plants can invade and colonize the site. In most cases, fine-grained dredged material contains large amounts of nitrogen and phosphorus, which promote vigorous plant growth. Elevations in confined disposal sites can range from wetland to upland terrestrial environments. In many cases, the dredged material was placed in upland disposal sites because contaminants were present in the dredged material. Consequently, there is potential for movement of contaminants from the dredged material into the environment through plants and then eventually into the food chain.

59. An appropriate test for evaluating plant uptake of contaminants from dredged material must consider the ultimate environment in which the dredged material is placed. The physicochemical processes become extremely important in determining the availability of contaminants for plant uptake.

60. There is a plant bioassay test protocol that was developed under the LEDO Program based on the results of the DMRP. This procedure has been applied to a number of contaminated dredged materials (both fresh water and estuarine). Results obtained from these plant bioassays have provided sufficient information to confirm the usefulness of the technique for predicting the potential for plant uptake of contaminants from dredged material (Folsom and Lee 1981, 1983; Folsom, Lee, and Preston 1981; Lee, Folsom, and Engler 1982). The procedure is presently being field verified under the CE/EPA FVP and is being applied to a wide variety of contaminated materials such as sewage sludge amended soils in the United States and metal mining waste contaminated soils in Wales, U. K.

61. The plant bioassay procedure requires taking a sample of sediment from a waterway and placing it either in a flooded wetland environment or an upland terrestrial environment in the laboratory. An index plant, *Spartina alterniflora* for estuarine sediments and *Cyperus esculentus* for freshwater sediments, is then grown in the sediment under conditions of both wetland and upland disposal environments. Plant growth, phytotoxicity, and bioaccumulation of contaminants are monitored during the growth period. Plants are harvested and analyzed for contaminants. The test results indicate the potential for plants to become contaminated when grown on the dredged material in either a wetland or upland terrestrial environment. From the test results, appropriate management strategies can be formulated as to where to place a dredged material to minimize plant uptake or how to control and manage plant species on the site so that desirable plant species that do not take up and accumulate contaminants are allowed to colonize the site, while undesirable plant species are removed or eliminated.

62. There is another laboratory test being developed under the LEDO Program that utilizes an organic extractant of dredged material to chemically predict plant uptake of certain trace metals such as zinc, cadmium, nickel, chromium, lead, and copper. This test procedure attempts to simulate the capacity of a plant root to extract metals from a dredged material. Field verification of this test protocol is being conducted under the CE/EPA FVP. This

test procedure takes a sample of dredged material in the flooded reduced wetland condition and another sample that has been air dried for an upland condition. The samples are extracted for 24 hr in a modified diethylenetriaminepentaacetic acid (DTPA) extraction solution according to Lee, Folsom, and Bates (1983). This solution is then filtered through a millipore filter and the filtrate is analyzed for soluble contaminants. This procedure has been successful in predicting plant leaf tissue contents of certain metals. There is no existing extraction procedure that predicts plant availability of organic contaminants.

63. Animal uptake. Many animal species invade and colonize upland dredged material disposal sites. In some cases, prolific wildlife habitats have become established on these sites. These habitats are usually rich in waterfowl and often become the focus of public interest through local ornithologists, sportsmen, and the environmentally aware public. Concern has developed recently over the potential for invertebrate animals inhabiting upland terrestrial disposal sites to become contaminated and contribute to the contamination of food webs associated with the site.

64. An appropriate test for evaluating animal uptake of contaminants from dredged material must consider the ultimate environment in which the dredged material is placed, the anticipated ecosystem developed, and the physicochemical processes governing the biological availability of contaminants for animal uptake.

65. There is a recommended test protocol being tested under the CE/EPA FVP that utilizes an earthworm as an index species to indicate toxicity and bioaccumulation of contaminants from dredged material. In this procedure, an earthworm is placed in sediment maintained in moist and semi-moist air-dried environments. The toxicity and bioaccumulation of contaminants are monitored over a 28-day period (Marquenie and Simmers 1984; Simmers, Rhett, and Lee 1983). This procedure is a modification of a procedure developed by Dr. C. A. Edwards in England for determining the hazardous nature of manufactured chemicals to be sold in the European Economic Community. Test results to date indicate the terrestrial earthworm test procedure can indicate potential environmental effects of dredged material disposal in upland environments. The evaluative portion of the test is mainly tissue analysis rather than strictly mortality. While the test is being established, those treatments necessary to ensure survival for the test period (such as washing or dilution) suggest

potential field site management strategies. The earthworm contaminant levels can also be related to the food web that could exist on the site after disposal. This type of test can be conducted simultaneously under optimum conditions in the laboratory and in the field at or near the proposed disposal site to further assess the extent of contaminant mobility. This test can identify bioavailable metals and organic contaminants in the material to be dredged.

Cost of conducting test protocols

66. An example of the cost and time required to conduct each test protocol is estimated in Table 1. Dollar amounts are considered as 1984 dollars. General assumptions made to calculate costs were that the equipment and facilities to conduct the test were available. Therefore, equipment costs are not included. In addition, each sediment sample was considered to be tested in four replicates to ensure some degree of precision. Cost to conduct the test will vary from one part of the nation to another. Chemical analysis costs will also vary across the nation. Cost varies with the number of samples and the number of parameters determined. In most cases, a fewer number of composited sediment samples can be evaluated to give an indication of potential contaminant mobility from sediments to be dredged. In addition, a fewer number of contaminants determined, especially organic compounds, will reduce the chemical analysis cost. Table 1 clearly illustrates the enormous cost that can be developed from the chemical analysis of samples. While it may cost approximately $48,000 to obtain samples for the suite of tests, chemical analysis costs for the sample generated could mount to between $125,000 and $187,000. Leachate test costs are high because the leachate test is under development and an accurate cost estimate is extremely difficult to project. Leachate test cost should be lowered when a routine test is available. Costs in Table 1 can be generated from the testing of only one sediment sample. Additional sediment samples will increase these costs proportionally, rapidly escalating the chemical analysis costs.

67. While Table 1 lists all of the test protocols that could be applied to a contaminated sediment, the decisionmaking framework to be discussed in the next section of this report will discuss when one or more of the test protocols should actually be conducted. From those test results, the framework will discuss and indicate additional test protocols that should then be conducted, if warranted.

Contaminant detection limits

68. Table 2 presents the detection limits for contaminants identified by Tetra Tech (1984) as being of potential concern in Commencement Bay that generally could be used in the chemical analyses of samples from the test protocols. Not all of these will be identified as contaminants of real concern in any specific sediment. All of the detection limits for water samples listed in Table 2 are for procedures approved by EPA for compliance with requirements of the National Pollutant Discharge Elimination System and the National Interim Primary Drinking Water Regulations and described in 40 CFR Part 136. These detection limits are based on relatively clean samples with few interferences. In general, detection limits are determined primarily by sensitivity of the analytical instrument (which is fixed), the degree of contamination, and the mass of sample available for extraction or digestion. Most of the detection limits for metals may be achieved using an atomic absorption spectrometer equipped with a heated graphite furnace or an inductively coupled plasma emission spectrometer. Detection limits for mercury are obtained using a cold vapor technique with the atomic absorption spectrometer. The detection limits for the organics (except pesticides and PCBs) are for gas chromatography/mass spectrometry (GC/MS) procedures using 1 ℓ of water or 50 g of solid material. The lower detection limits cited for pesticides and PCBs are based on GC/Electron Capture Detection (GC/ECD) procedures. Although all of these procedures have been in use for a number of years at laboratories analyzing environmental samples, most require analysts who are experienced in the methodology and who are acquainted with the interferences that can alter results. Levels of detection can be lowered by up to a factor of ten in many cases by further concentration and cleanup of samples. Further lowering of detection levels will require the use of more recently developed techniques and experienced analysts.

Decisionmaking Framework

69. A decisionmaking framework is presented in detail in Appendices A and B that utilizes the management strategy as illustrated in Figure 1 and incorporates the results from the suite of test protocols described in paragraphs 23-65 into ten flowcharts. These appendices discuss in detail the

steps to be followed in using the flowcharts. Relevant information and data have been compiled in a number of tables in Appendix C. The information and data are used to make the decisions called for in the framework. Appropriate cross referencing of paragraphs and appendix tables has been incorporated into the flowcharts to assist the user in stepping through the framework and in and out of associated tabular information. Terms that will be used in the framework include:

a. *Reference site--location from which biological and sediment or water chemistry data are used for comparison to test results from contaminated dredged material. This may vary from an existing disposal site to an existing background site and will be determined by a local authority decision.*

b. *Local authority decision (LAD)--a decision made by local regulatory authorities having jurisdiction over the project in question.*

Responsibility for local authority decisions

70. There are certain decisions that must be made initially and then periodically within the decisionmaking framework that are the sole responsibility of the local authorities. These local authority decisions (LADs) are required to initially set specific goals to be achieved. For example, a LAD must establish the environmental quality ultimately desired at the site and the rate at which this goal is to be achieved. A LAD must determine the appropriate reference site(s) for test result comparisons in the decisionmaking framework in order to achieve the ultimate and intermediate goals. As described previously, the selection of reference sites can vary from the actual disposal site to a pristine background site. This selection is dependent on the goal established for the area such as a goal of nondegradation (reference site is disposal site) or cleaner-than-present condition (reference site is pristine background site) or some other goal. *The clear identification of the ultimate and intermediate goals and selection of appropriate references to achieve them is a crucial responsibility of the local authorities and will influence the outcome of all test result interpretations.* In addition, LADs must be made whenever technical knowledge and understanding are inadequate to support a scientific decision. In such cases a regulatory decision must be made by local authorities on the basis of a combination of scientific judgement and administrative considerations. For example, a LAD must determine whether or not to consider mixing zones when test results

exceed reference site values or water-quality criteria. Should the LAD be to consider mixing zones and an acceptable mixing zone is available, a decision for no restrictions on that particular aspect of the disposal might be made. In contrast, should the LAD be not to consider mixing zones, then a decision for restrictions might be made which will generally be more conservative but may prove to be more costly upon implementation of the restrictions. Many of these LADs are shown in the flowcharts as diamonds ◇ . Scientific guidance for making each LAD is provided at the appropriate points in the text. This general guidance is appropriate for nationwide use, but the actual implementation of the general guidance must vary in different areas to meet different local goals, objectives, and concerns. The general guidance for each LAD is followed by a paragraph describing the initial approach to making the LAD tentatively selected by Commencement Bay area local authorities for use at the Commencement Bay Nearshore/Tideflats Superfund Site, Washington. For the Commencement Bay area, the WDOE Superfund Project Manager has established the quantitative guidance for LADs reported in this document after considering local input from other WDOE staff, the Seattle District Corps of Engineers, EPA Region X, and other scientists. The quantitation of the LAD guidance facilitates objective decisionmaking, but may oversimplify complexly interactive considerations. Consequently, the authors have attempted to present examples of test result interpretations in light of the tentative Commencement Bay area authorities' LADs. *The examples are illustrations and should not be construed as being advocated by the authors or as being final guidance.*

Initial evaluation of contaminants

71. The initial evaluation determines if the sediment to be dredged is likely to be contaminated (Figure 4). This decision is based on consideration of available information as described in paragraph 14. The information considered in the initial evaluation also allows identification of the specific contaminants of concern in each sediment being considered.

72. It is recommended that all potential dredging projects collect at least one composited sediment sample from the project. This sample should be representative of the entire depth of dredging as well as the reach of waterway to be dredged. An example of a composited sample might be the collection

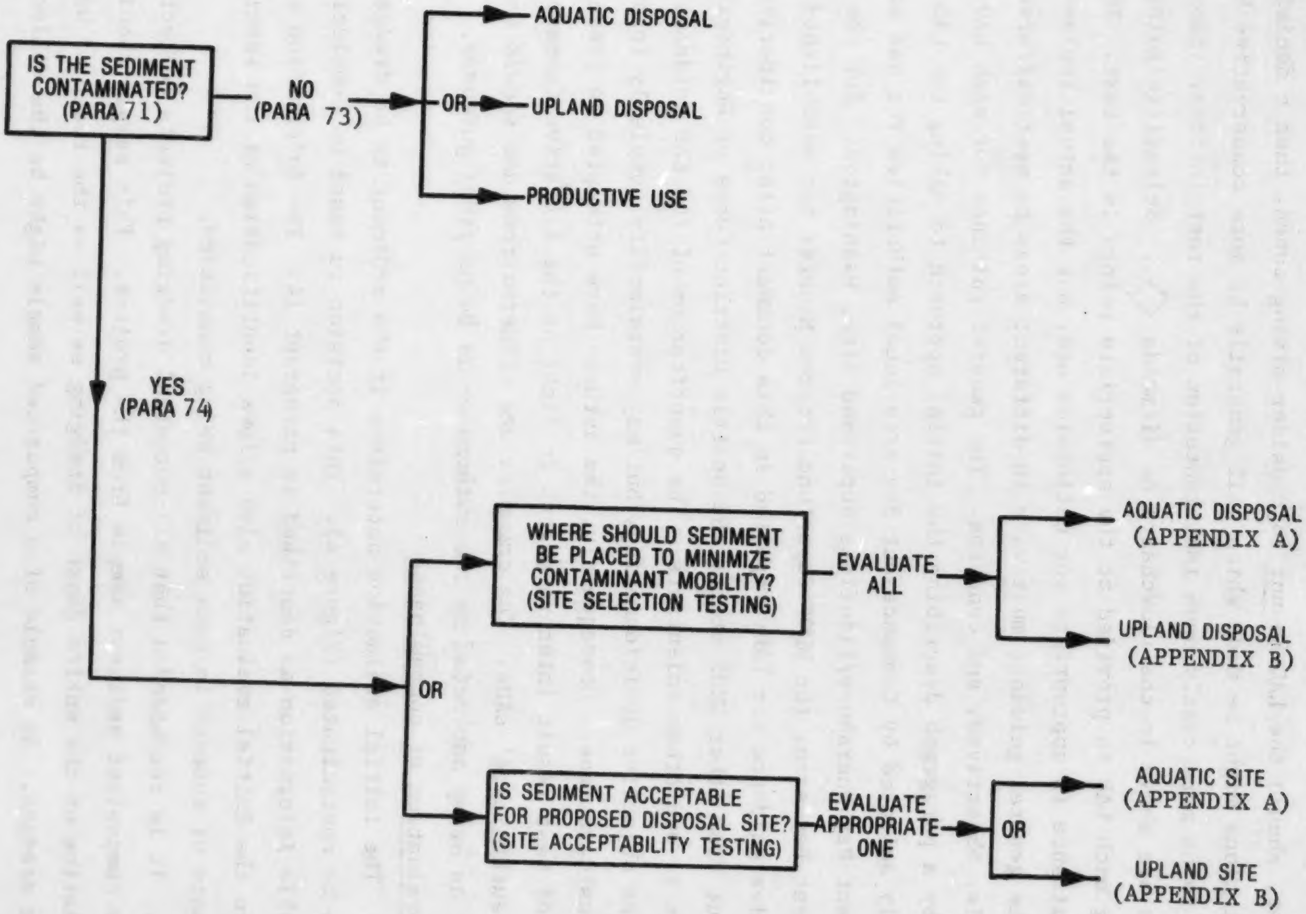
IS THE SEDIMENT CONTAMINATED? (PARA 71)
NO (PARA 73)
OR
AQUATIC DISPOSAL
UPLAND DISPOSAL
PRODUCTIVE USE
YES (PARA 74)
OR
WHERE SHOULD SEDIMENT BE PLACED TO MINIMIZE CONTAMINANT MOBILITY? (SITE SELECTION TESTING)
EVALUATE ALL
AQUATIC DISPOSAL (APPENDIX A)
UPLAND DISPOSAL (APPENDIX B)
IS SEDIMENT ACCEPTABLE FOR PROPOSED DISPOSAL SITE? (SITE ACCEPTABILITY TESTING)
EVALUATE APPROPRIATE ONE
OR
AQUATIC SITE (APPENDIX A)
UPLAND SITE (APPENDIX B)

Figure 4. Flowchart for initial decisions for using framework

of a sediment core for each 8,000 cu yd* of sediment along the waterway. This would be the equivalent of two typical barge loads of dredged material. These cores are then divided in half lengthwise. One half of all the cores are kept separate while the other half of all cores are mixed to get a homogeneous composited sample. This sample is then analyzed for the entire list of EPA priority pollutants. If the composite sample indicates elevation of one or more contaminants, then each separate remaining half core can be analyzed to determine which sample or samples along the waterway contains contaminants. Likewise, a composited sediment sample should be obtained from an appropriate LAD reference site and analyzed for the entire list of EPA priority pollutants. Further details on sediment sampling and processing procedures are reported by Plumb (1981).

73. DECISION OF NO CONTAMINATION.** *If sufficient information is available and provides no substantive reason to believe contaminants are present above reference site levels and based on the chemical analysis of a composite sediment sample*, a DECISION FOR NO FURTHER TESTING is made. The sediment can be dredged and disposed in an aquatic site, in an upland site, or used productively such as for marsh creation or enhancement of agricultural land with *no restrictions and no contaminant impacts on the environment*. In such cases, the selection of a disposal site is based on considerations other than potential contaminant impacts on the environment.

74. DECISION OF SEDIMENT CONTAMINATION. *If the available information is inadequate or provides a substantive reason to believe contaminants are present above reference site levels*, then a DECISION FOR FURTHER TESTING is made. The testing of the sediment depends on which of the two questions in Figure 4 is being addressed. The question *"In what type of disposal environment should the sediment in question be placed to minimize contaminant mobility?"* is *SITE SELECTION TESTING* and represents the situation where aquatic and upland (and nearshore) disposal sites are available. The emphasis is on selecting the disposal environment minimizing the potential for adverse

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* A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page 13.

** All decisions reached on the basis of test results and interpretations are indicated in UNDERLINED CAPITAL LETTERS.

contaminant impacts from the dredged material. The second question, *"Is this sediment suitable from a contaminant perspective for placement in a particular disposal environment?"*, could be considered as *SITE ACCEPTABILITY TESTING* and addresses the situation that there are limitations on available disposal sites. Therefore, the sediment is tested to determine the acceptability of a given disposal environment for the disposal of the sediment. For example, if the only disposal sites available are upland sites, then testing should focus on upland disposal and not on aquatic disposal. Ultimately, the testing should be tailored to the available disposal site. Once the appropriate question is identified, a decision to consider AQUATIC DISPOSAL (Appendix A) or UPLAND DISPOSAL (Appendix B) can be made. In Appendices A and B, test results are compared to established numerical values where these are available and appropriate for test interpretation. When such values do not exist, these appendices provide guidance on interpreting test results in comparison to results of the same test performed on a reference sediment selected in accordance with paragraph 70. For each test, guidance is provided on these bases for determining whether or not restrictions on the discharge are required to protect against contaminant impacts or whether further evaluation is required to determine the need for restrictions. In some case, there is inadequate scientific knowledge to reach a decision solely on the basis of test results, and LADs that incorporate both scientific and administrative judgements are required to reach a decision. In such cases, guidance is given on evaluating the scientific considerations involved. In this manner guidance is provided for systematically interpreting the results of each test required to evaluate potential impacts of aquatic disposal (Appendix A) and upland disposal (Appendix B). Applying the systematic detailed guidance of Appendices A and/or B will lead to a decision that restrictions are or are not required for aquatic disposal and/or upland disposal. Possible restrictions to minimize the potential impact of aquatic disposal are discussed in paragraphs 75-80. Cross-references in Appendix A refer to specific one(s) of these paragraphs where appropriate. Possible restrictions to minimize the potential impacts of upland disposal are discussed in paragraphs 81-97. These paragraphs are referred to specifically in Appendix B wherever appropriate.

Aquatic disposal with restrictions

75. In cases where testing protocols indicate that water column or benthic effects will be unacceptable when conventional aquatic disposal techniques are used, aquatic disposal with restrictions may be considered. This alternative involves the use of dredging or disposal techniques that will reduce water column and benthic effects. Such techniques are discussed in detail in US Army Engineer District, Seattle (1984) and include use of submerged discharge points and diffusers, subaqueous confinement of material, or capping of contaminated material with clean material, and treatment techniques. The same basic considerations for conventional aquatic disposal site designation, site capacity, and dispersion and mixing also apply to aquatic disposal with restrictions.

Submerged discharge

76. The use of a submerged point of discharge reduces the area of exposure in the water column and the amount of material suspended in the water column and susceptible to dispersion. The use of submerged diffusers also reduces the exit velocities for hydraulic placement, allowing more precise placement and reducing both resuspension and spread of the discharged material. Considerations in evaluating feasibility of a submerged discharge and/or use of a diffuser include water depth, bottom topography, currents, type of dredge, and site capacity. The DMRP (Barnard 1978) developed a conceptual design for a submerged diffuser that has been successfully demonstrated by European dredging interests and is now being considered for more detailed study in the United States under the CE Dredging Operations Technical Support (DOTS) Program.

Subaqueous confinement

77. The use of subaqueous depressions or borrow pits or the construction of subaqueous dikes can provide confinement of material reaching the bottom during aquatic disposal. Such techniques reduce the areal extent of a given disposal operation, thereby reducing both physical benthic effects and

the potential for release of contaminants. Considerations in evaluating feasibility of subaqueous confinement include type of dredge, water depth, bottom topography, bottom sediment type, and site capacity. Subaqueous confinement has been utilized in Europe and to a limited extent by the CE's New York District. Precise placement of material and use of submerged points of discharge increase the effectiveness of subaqueous confinement.

Capping

78. Capping is the placement of a clean material over material considered contaminated. Considerations in evaluation of the feasibility of capping include water depth, bottom topography, currents, dredged material and capping material characteristics, and site capacity. Both the Europeans and the Japanese have successfully used capping techniques to isolate contaminated material in the aquatic disposal environment. Capping is also currently used by the CE New York District and CE New England Division as a means of offsetting the potential harm of aquatic disposal of contaminated or otherwise unacceptable sediments. The London Dumping Convention has accepted capping, subject to careful monitoring and research, as a physical means of rapidly rendering harmless contaminated material disposed in the ocean. The physical means are essentially to seal or sequester the unacceptable material from the aquatic environment by a covering of acceptable material.

79. The efficiency of capping in preventing the movement of contaminants through this seal and the degradation of the biological community by leakage, erosion of the cover (cap), or bioturbation are being addressed by research under the LEDO Program. The engineering aspects of cap design and placement are also being addressed under this program. It is possible that techniques and equipment can be developed that will provide a capped dredged material disposal area as secure from potential environmental harm as upland confined disposal areas. The capping technique for disposal of dredged material has potential for relieving some pressure on acquiring sites for confined disposal areas in localities where land is rapidly becoming unavailable.

Chemical/physical/biological treatment

80. Treatment of discharges into open water may be considered to reduce certain impacts. For example, the Japanese have used an effective in-line

dredged material treatment scheme for highly contaminated harbor sediments (Barnard and Hand 1978). However, this strategy has not been widely applied and its effectiveness has not been demonstrated for solution of the problem of contaminant release during aquatic disposal.

Upland disposal with restrictions

81. Conventional confined upland disposal methods can be modified to accommodate disposal of contaminated sediments in new, existing, and reusable disposal areas. The design or modification of these areas must consider the problems associated with contaminants and their effects on conventional design. Many of the following design considerations apply to all of the implementation options.

Site selection and design

82. Site location is an important consideration since it can mitigate many contaminant mobilization problems. Proper site selection may reduce surface runon and therefore contaminated runoff and contaminant release by flooding. Ground-water contamination problems can be minimized through selection of a site with natural clay foundation instead of a sandy area and through avoidance of aquifer recharge areas (Gambrell, Khalid, and Patrick 1978).

83. Careful attention to basic site design as discussed previously will aid in implementing many of the controls outlined. Retention time can be increased to improve suspended solids removal and, therefore, contaminant removal. Additional ponding depth can also improve sedimentation. Decreasing the weir loading rate and improving the weir design to reduce leakage and control the discharge rate can also reduce the suspended solids and contaminant concentration of the effluent.

84. Dewatering should be examined carefully before selecting a method since dewatering promotes oxidation of the material and thereby increases the mobility of certain contaminants (Gambrell, Khalid, and Patrick 1978). Care must also be taken to reduce loss of contaminated sediment by erosion during drainage and storm events.

Available options

85. Depending on the particular dredging operation, one or more types of restrictions may be required. The particular restriction or combination of restrictions may eliminate certain disposal options. For the purposes of developing a management strategy, four options are considered available for upland disposal with restrictions. These options include:

- a. Containment--dredged material and associated contaminants are contained within the disposal site.
- b. Treatment--dredged material is modified physically, chemically, or biologically to reduce toxicity, mobility, etc.
- c. Storage and rehandling--dredged material is held for a temporary period at the site and later removed to another site for ultimate disposal.
- d. Reuse--dredged material is classified and beneficial uses are made of reclaimed materials.

Obviously, combinations of the above options are available for a particular dredging operation.

86. Containment of contaminated dredged material can be either in an existing or a new facility. These facilities can be designated or modified to handle a wide variety of contaminants. Most contaminated sediments can be disposed of in an existing site where special controls have been incorporated in consideration of the restrictions discussed in paragraphs 91-97. In the case of highly contaminated sediments, a more secure disposal facility would be required, and, in all probability, disposal restrictions would dictate the design of a new facility.

87. The treatment option can be associated with either existing or new facilities. Some form of physical, chemical, or biological treatment would probably be associated with the disposal of highly contaminated dredged material. Treatment may also be combined with other options for disposal of slightly to moderately contaminated dredged material in confined disposal sites.

88. Of the four available options, storage and rehandling can serve two beneficial functions: continued use of upland sites located close to dredging areas and use as a rehandling facility for contaminated dredged material prior to later disposal offsite.

89. Finally, the concept of a reuse option would incorporate beneficial uses of materials reclaimed by the classification/separation process. Such

materials could include sand and gravel or slightly contaminated construction fill to be used for raising dikes or acceptable offsite uses.

Design considerations

90. Contaminated dredged material management includes methods for dewatering, transporting, storing, treating, and disposing of contaminated material. The most technically and economically effective strategy to handle contaminated dredged material will depend on many site-specific variables, which include the following:

a. Method of dredging used--hydraulic versus mechanical.

b. Method of dredged material transport--pipeline versus truck or hopper or barge.

c. Physical nature of removed material--consistency (solids/water content) and grain-size distribution.

d. Volume of removed material.

e. Nature and degree of contamination; physical and chemical characteristic of contaminants.

f. Proximity of acceptable treatment, storage, containment, or reuse facilities.

g. Available land area for construction of new or expansion of existing facilities.

Restrictions

91. Conventional confined upland disposal methods may be modified to accommodate disposal of slightly to highly contaminated sediments. Many of the restrictions on upland disposal that may be required are common to the available options. Among these restrictions are:

a. Effluent-quality controls during dredging operations.

b. Runoff water-quality controls after dredging operations.

c. Leachate controls during and after dredging operations.

d. Control of contaminant uptake by plants and animals during and after dredging operations.

e. Control of atmospheric contaminants after dredging operations.

92. Many of the contaminant controls described in the following paragraphs are directly applicable to the control of highly contaminated sediments. These controls will be extremely site specific. Special considerations that

are based on the physical nature and chemical composition of the dredged material will be required to effectively design a confined disposal facility. For example, some contaminated dredged material may require in-pipeline treatment prior to discharging the material into the containment facility. Similarly, if the facility requires a bottom-liner system, the liner materials (synthetic membrane or clay) must be chemically compatible (resistant) with the dredged material to be placed on them. Special compatibility testing will be needed for selection of appropriate liner materials. Other requirements such as leachate detection and monitoring are likely due to the potentially adverse environmental effects of the liner leaking.

93. Effluent controls. Effluent controls at conventional upland disposal areas are generally limited to chemical clarification. The clarification system is designed to provide additional removal of suspended solids and associated adsorbed contaminants as described in Schroeder (1983). Additional controls can be used to remove fine particulates that will not settle or to remove soluble contaminants from the effluent. Examples of these technologies are filtration, adsorption, selection ion exchange, chemical oxidation, and biological treatment processes. Beyond chemical clarification, only limited data exist for treatment or dredged material (Gambrell, Khalid, and Patrick 1978).

94. Runoff controls. Runoff controls at conventional sites consist of measures to prevent the erosion of contaminated dredged material and the dissolution and discharge of oxidized contaminants from the surface. Control options include maintaining ponded conditions, planting vegetation to stabilize the surface, liming the surface to prevent acidification and to reduce dissolution, covering the surface with synthetic geomembranes, and/or placing a lift of clean material to cover the contaminated dredged material (Gambrell, Khalid, and Patrick 1978).

95. Leachate controls. Leachate controls consist of measures to minimize ground-water pollution by preventing mobilization of soluble contaminants. Control measures include proper site selection, dewatering to minimize leachate production, chemical admixing to prevent or retard leaching, lining the bottom to prevent leakage and seepage, capping the surface to minimize infiltration and thereby leachate production, using vegetation to stabilize contaminants and to increase drying, and leachate collection, treatment, or recycling (Gambrell, Khalid, and Patrick 1978).

96. Control of contaminant uptake. Plant and animal contaminant uptake controls are measures to prevent mobilization of contaminants into the food chain. Control measures include selective vegetation to minimize contaminant uptake, liming or chemical treatment to minimize or prevent release of contaminants from the material to the plants, and capping with clean sediment or excavated material (Gambrell, Khalid, and Patrick 1978).

97. Control of atmospheric contaminants. The control of gaseous emissions or dust that might present human health hazards can consist of physical measures such as covers or vertical barriers. Control of contaminated surface materials is another type of management or operating control to minimize transport of contaminants offsite. Techniques for limiting wind erosion are generally similar to those employed in dust control and include physical, chemical, or vegetative stabilization of surface soils (CE 1983, Lee et al. 1984).

PART III: EXAMPLE APPLICATION OF FRAMEWORK AND INTERPRETATION OF TEST RESULTS

Disposal Environment Descriptions

98. In order to apply the decisionmaking framework and to illustrate the integration of test results to evaluate proposed disposal options or to select among alternatives, it is necessary to have results for the tests described in Part II for several sediments and disposal environments. This example utilizes a hypothetical scenario involving sediments and disposal environments under consideration in Commencement Bay, Washington. The disposal sites being considered are described below.

Aquatic environment

99. An aquatic site is located midway between the mouth of a major waterway and the northern part of the bay about 3/4 of a mile from the nearest shoreline. Depths range between 100 and 200 ft at mean lower low water (MLLW). The site is a natural horseshoe-shaped depression; closing the fourth side with an underwater dike would provide capacity for disposing and capping of over 2.5 million cu yd of dredged material. Ownership of the site is with the State of Washington, but there is little practical control over potential long-term use of the site. The site is within 2 miles of major dredging areas. No other major discharge sites are nearby that could result in cumulative impacts. Water column temperatures of 9 to 12° C are usual at the site. Surface salinity varies from a winter/spring low of 14 ppt to a summer high of 27 to 30 ppt. Bottom salinity remain close to 30 ppt year round.

100. Local fishermen indicate that the area is popular for bottom fishing though success is unknown. While the depths are outside the normal feeding range of salmonids migrating over the site, the local native American tribe indicates that the upper water column is seasonally used by drift netters. Human activity directly affecting the site bottom has not been recorded. However, past and present use of the water surface for extensive log booming may have influenced bottom sediment composition. Moderate to high recreational shellfishing occurs along the nearest shoreline to the site; however, there is no other human water-contact activity. The site is not regarded as a major spawning or nursery area.

Upland environment

101. A 60-acre upland disposal site is bounded by roads on the northeast and northwest and by a railroad switchyard on the southeast. The site

was formerly a dredged material disposal area and has been filled to approximately +16 ft MLLW. The top 10 to 15 ft of the site is composed of loose fill containing coarse sand, gravel, and debris. Under the fill is found a 10-ft-thick layer of silt; below that is found dense sand. Filling of the site to industrial grade found in adjacent lands would provide capacity of 100,000 cu yd; fill to +35 ft MLLW (a likely maximum) would provide capacity for an additional 1,450,000 cu yd. The site is centrally located and within 1 mile from major dredging areas. Ownership is by the local Port Authority, and the area is zoned for port industrial area development. A relatively new warehouse and office facility exists on an elevated corner of the site. However, there is little firm regulatory control over future site use.

102. Effluent discharge from hydraulic disposal in this site would be directed through an existing drainage canal to the nearby navigation waterway, which also receives other major discharges. Due to recent use of this site as a disposal area, the area contains a sparse mixture of upland grasses and exposed sandy dredged material, but it does not serve as wildlife habitat. The area is suspected of being a recharge area for a shallow aquifer, but there are no wells in this aquifer at present.

Nearshore environment

103. In addition to the aquatic and upland sites described above, consideration is also being given to closing off and filling Milwaukee Waterway, a dead-end channel excavated into the shoreline of Commencement Bay. The Milwaukee Waterway nearshore disposal area is a 30-acre navigation waterway separated from the major bay river on the south and another actively used waterway on the north by finger fills overlying tide flats. The top 15 to 20 ft of the finger fills along the sides of the waterway are composed of loose and coarse fill. Below the fill is found a layer of softer silt, varying in thickness from 10 to 30 ft. Dense sand is further below. The bottom of the waterway is mostly covered with approximately 5 ft of soft organic mud. Consolidated silt (20 ft thickness) underlies the surface silt, with sand further below. Salinity of the nearby water is similar to that of the aquatic site. Average site elevation is -26 ft MLLW. Elevation of adjacent fill surfaces is +18 ft MLLW. Wet capacity (area that would remain tidally influenced and saturated) is 1,870,000 cu yd; dry capacity is 290,000 cu yd to industrial grade. Owned by the local Port Authority, the site is intended to be filled

to accommodate a container terminal facility, but there is no control over site use. The site is within 1 mile of major dredging areas.

104. There is little probability of wildlife use of the site. Little aquifer recharge is expected here. The site is near seasonal fish migration routes, but it is not used as a spawning or nursery area. There is no human water-contact activity, but some recreational shell fishing occurs near the site. There are no wells in the area.

105. If the Milwaukee Waterway is filled with dredged material, the physicochemical conditions controlling contaminant mobility will be a combination of those occurring under aquatic and upland disposal. Three distinct physicochemical environments will develop after the filling operation and can be described as:

a. Upland--dry unsaturated layer.

b. Intermediate--partially or intermittently saturated layer.

c. Flooded--totally saturated layer.

106. Initially, all of the dredged material will be saturated, anaerobic, and reduced when placed in Milwaukee Waterway. After the filling operation is completed, the upper surface layer of dredged material above the high tide elevation will become upland. The layer of dredged material between the high tide and low tide elevations will become an intermediate layer with a moisture content varying between saturated and unsaturated. The degree of moisture will depend on the rate of water movement in, through, and out of this layer. The layer of dredged material at and below the low tide elevation will remain saturated. Potential pathways of contaminant mobility are illustrated in Figure 5. The three physicochemical environments that will develop at this disposal site are also indicated.

107. The test protocols for predicting contaminant mobility at the Milwaukee Waterway disposal site should address the pathways illustrated in Figure 5. Test protocols similar to those described under upland disposal (paragraphs 41-65) should be applied to dredged material placed at the Milwaukee Waterway disposal site. The following tabulation lists the specific test protocol and the pathway of contaminant mobility from Figure 5 addressed:

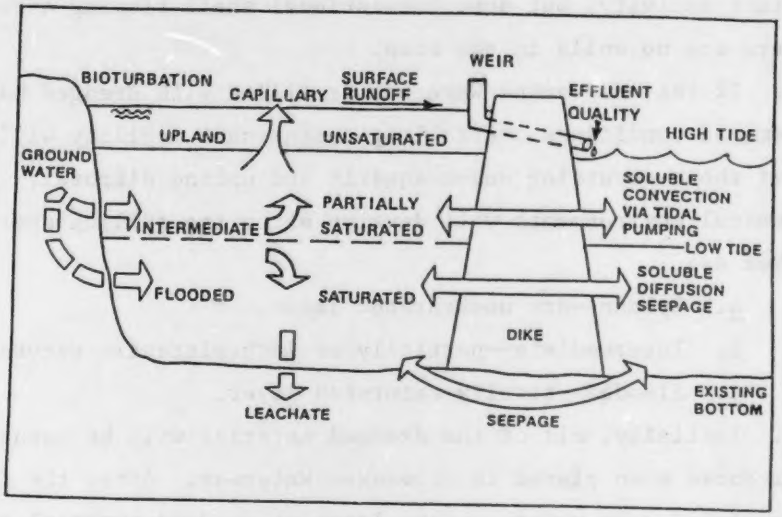
BIOTURBATION
SURFACE RUNOFF
CAPILLARY
WEIR
EFFLUENT QUALITY
UPLAND
UNSATURATED
HIGH TIDE
GROUND WATER
SOLUBLE CONVECTION VIA TIDAL PUMPING
PARTIALLY SATURATED
INTERMEDIATE
LOW TIDE
SOLUBLE DIFFUSION SEEPAGE
FLOODED
SATURATED
DIKE
EXISTING BOTTOM
LEACHATE
SEEPAGE

Figure 5. Nearshore-disposal filling of Milwaukee Waterway

Test Protocol	Pathway of Contaminant Mobility
Effluent quality	Effluent discharge
Surface runoff quality	Runoff
Leachate quality	Leachate
	Seepage
	Soluble diffusion, seepage
	Soluble convection via tidal pumping
	Capillary
	Mobility between layers
Plant uptake	Bioturbation
Animal uptake	Bioturbation

These test results for sediments scheduled to be dredged in Commencement Bay will provide appropriate information to indicate which sediments should be placed in the flooded, intermediate, and upland layers at the Milwaukee Waterway disposal site in order to minimize contaminant mobility according to the pathways illustrated in Figure 5.

Sediment Description

108. In addition to descriptions of disposal environments, example application of the decisionmaking framework also requires test results for several sediments. While all the tests of Part II have been performed on various sediments, no single sediment has been analyzed by more than a few of the tests. Therefore, Puget Sound sediments were reviewed on the basis of existing bulk chemistry data. On the basis of these data, one sediment was selected as a hypothetical reference sediment and three sediments with different concentrations of various types of contaminants were selected as hypothetical test sediments.

109. On the basis of the considerations discussed in paragraph 14, 16 contaminants were chosen for illustrative purposes as contaminants of concern. These contaminants are potentially environmentally important and include a spectrum of metals and hydrocarbons, encompassing the acid extractable, pesticide, and base-neutral fractions, including one- through five-ring compounds. When data were not available for some of the contaminants selected, hypothetical values were substituted that appeared reasonable on the basis of other sediments similarly contaminated with the compounds for which data were available.

110. The complete hypothetical bulk chemistry obtained in this manner for the four sediments was presented to scientists familar with the various tests of Part II. Recognizing that the results of other tests cannot accurately be predicted on the basis of bulk chemistry alone, these scientists were asked to provide hypothetical examples of possible test results that would not seem unreasonable if the tests had actually been performed on sediments with the hypothetical chemical concentrations. This provided the hypothetical example values in Tables 3-21. *These tables are used here only for hypothetical illustration of the procedures for interpreting test results and cannot be used for any other purpose.*

Example Interpretation of Results

111. Approach. The interpretation of hypothetical test values presented for example test sediments A, B, and C is purely for purposes of illustrating the decisionmaking framework. The hypothetical test results presented in Tables 3-21 for sediments A, B, and C were interpreted according to the guidance in Appendices A and B in order to arrive at the illustrative results that follow. *For this illustration the authors have assumed the role of the local authority for all LADs and have made those decisions according to the initial approach tentatively selected by Commencement Bay area local authorities. This approach is discussed conceptually in paragraph 69 and described quantitatively at the appropriate points throughout the document. However, these illustrative LAD decisions should not be construed as implied guidance or precedents for actual LADs.*

112. Discussion of possible Commencement Bay area local authority decision. *Commencement Bay area authorities have discussed a variety of potential goals for the environmental quality of Commencement Bay. While selection of the goal for Commencement Bay has not been made, one of the alternatives discussed was the goal of returning the bay to a cleaner environment as represented by relatively untouched areas of Puget Sound. For purposes of discussion and illustration in this report, the following interpretation of test results is based on this cleaner environment goal. Accordingly, local authorities have selected an example reference site from among the more pristine areas of Puget Sound. With this example goal, more dredged materials will be found to exceed reference values by wider margins, and thus restrictions will be required in more cases than if a less pristine reference site were chosen. This may often result in increased costs to implement the restrictions, but will not necessarily provide increased environmental protection. This is due to the fact that a relatively pristine area may be able to accept a considerable increase in contaminants before adverse effects result, and small elevations above reference may not be environmentally important. On the other hand, a less pristine reference area may already be sufficiently contaminated to produce adverse results.*

Example Interpretation of Results-Sediment A

113. *In the initial evaluation, Commencement Bay area authorities have tentatively decided to require a sediment bulk chemical analysis for the priority pollutants and a sediment toxicity test in addition to assessment of the points discussed in paragraph 14. If any contaminant were to exceed the concentration in the reference sediment by 1.5 times or more (paragraph 14) or if the sediment were more toxic than the reference sediment, testing would be required.* An advantage for doing this is that it would provide sediment-specific data at a very early point in the decisionmaking process. However, some disadvantages would be that the information may not be extremely useful at this point since it would be an insufficient basis for deciding that testing were not required if results were below those described above. In addition, these tests do not consider the potential for bioaccumulation and do not consider the geochemical changes and thus the potentially very different environmental impacts that would occur with upland disposal. Nor are these tests sufficient to impose restrictions at this point in the decisionmaking process. *In addition, Commencement Bay area authorities have tentatively decided that no further testing for disposal in upland environments is required for sediments containing those contaminants at concentrations equal to or less than the normal background concentration ranges for US cropland for which values have been established (Table C9).* An alternative approach is to assemble the available information discussed in paragraph 14 and decide whether it is adequate to conclude there is no reason to believe the test material is contaminated. Bulk chemical data would be specifically required in order to assist in this evaluation. If there is insufficient information to reach this conclusion or if there is information indicating there is reason to believe contaminants are present, then specific testing following the decisionmaking framework should be initiated. Sediment A was hypothetically much more highly contaminated with metals than any other of the test sediments (Table 14). It was also considerably higher in sand-sized particles and lower in clay than the reference sediment. This is probably at the outer limits of similarity in grain sizes required for valid comparisons between test and reference sediments. These must be roughly similar in grain size for bulk chemical comparisons since contaminants are naturally higher and more tightly associated with

clay than with sand. Therefore, a given contaminant concentration in clay is of less environmental concern than the same concentration would be in sand.

Aquatic disposal-sediment A

Water column evaluation

114. Commencement Bay area authorities have tentatively decided to place emphasis on effects as well as mass movement of contaminants. The implementation of this is illustrated in Figure 6. The effects assessment portion of this figure is identical to Figure A1*, except a mass loading assessment has been added. Hypothetically, the LAD might be that site- and sediment-specific water column testing is warranted (paragraph A2) due to the unusually high concentrations of metals in sediment A.

115. Chemical evaluations. Hypothetically, the LAD might be to conduct a chemistry-based evaluation of the potential for water column impacts (paragraph A2) since water-quality criteria exist for most of the metals, which are the primary contaminants of concern in sediment A.

116. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical elutriate test values (Table 3) for cadmium, copper, mercury, and zinc do not require restrictions (paragraph A6b). The hypothetical elutriate value for PCB requires a LAD (paragraph A6e). Hypothetically, the LAD for PCB might be for FURTHER EVALUATION by considering mixing, since there was high concern in relation to subparagraph A7a and moderate concern in subparagraph A7e. When the mixing zone required to dilute the PCB in the discharge to the acute criterion at the aquatic disposal site (paragraphs 99 and 100) is calculated (Appendix D, sediment A), it has the following characteristics:

a. Volume of 29,160 cu ft and surface area projection of 103,023 sq ft.
b. Plume 583 ft long by 190 ft wide parallel to shore.
c. Time to achieve dilution of 3.25 min.
d. One barge discharge every 3 hr around the clock.
e. Three-month dredging and disposal operation.
f. No municipal water intakes in Commencement Bay.

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* Alphanumeric identification refers similarly identified items in the appendices.

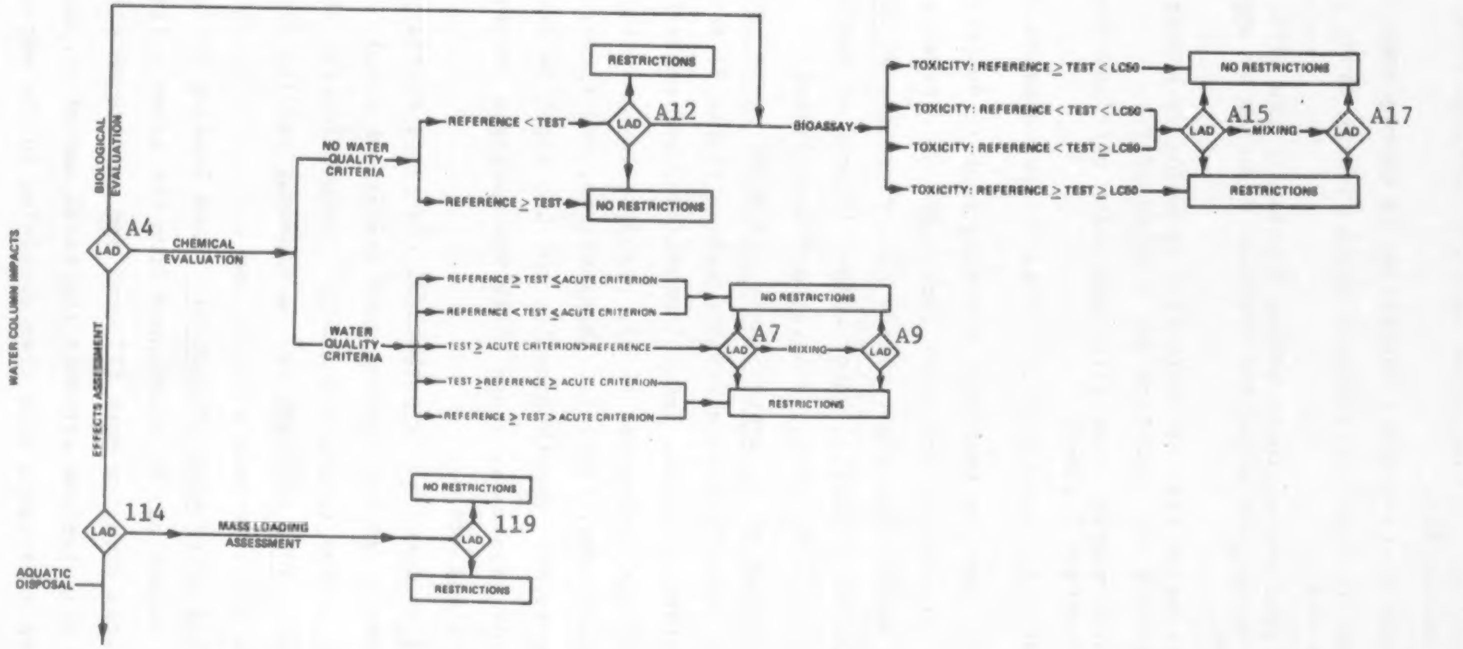

WATER COLUMN IMPACTS
AQUATIC DISPOSAL
LAD
114
EFFECTS ASSESSMENT
LAD
A4
BIOLOGICAL EVALUATION
CHEMICAL EVALUATION
NO WATER QUALITY CRITERIA
REFERENCE < TEST
REFERENCE ≥ TEST
LAD
A12
RESTRICTIONS
NO RESTRICTIONS
BIOASSAY
TOXICITY: REFERENCE ≥ TEST < LC50
TOXICITY: REFERENCE < TEST < LC50
TOXICITY: REFERENCE < TEST ≥ LC50
TOXICITY: REFERENCE ≥ TEST ≥ LC50
NO RESTRICTIONS
LAD
A15
MIXING
LAD
A17
RESTRICTIONS
WATER QUALITY CRITERIA
REFERENCE ≥ TEST ≤ ACUTE CRITERION
REFERENCE < TEST ≤ ACUTE CRITERION
TEST ≥ ACUTE CRITERION > REFERENCE
TEST ≥ REFERENCE ≥ ACUTE CRITERION
REFERENCE ≥ TEST > ACUTE CRITERION
NO RESTRICTIONS
LAD
A7
MIXING
LAD
A9
RESTRICTIONS
MASS LOADING ASSESSMENT
LAD
119
NO RESTRICTIONS
RESTRICTIONS

Figure 6. Flowchart for Seattle decisionmaking for aquatic disposal (water column impacts) (number near LAD is paragraph discussing LAD)

g. No potential drinking water aquifers recharge from Commencement Bay.

h. Low human water-contact activities in Commencement Bay.

i. Moderate to high recreational shell fishing along shore 1 mile away.

j. Year-round recreational bottom fishing at the site, seasonal drift netting of salmonids overlaps dredging by approximately 2 weeks.

k. Nearest major fish or shell fish spawning or nursery areas used during the operation are 6 miles away.

l. Salmonids migrate over site; migration overlaps dredging by approximately 2 weeks.

m. Nearest major discharge is sewage outfall 3 miles distant.

Hypothetically, the LAD might be that such a mixing zone is acceptable (paragraph A9a) in view of the considerations of paragraph 34. Therefore, the Commencement Bay area authorities might decide that there are NO RESTRICTIONS REQUIRED to protect against potential water column impacts of contaminants of concern for which water-quality criteria have been established.

117. Chemical evaluation of contaminants for which acute water quality criteria do not exist. Hypothetical elutriate values (Table 3) for pyrene, benzo(a)pyrene, hexachlorobutadiene, hexachlorobenzene, and pentachlorophenol do not require restrictions (paragraph A11a). Hypothetical elutriate values for arsenic, lead, naphthalene, fluorene, phenanthrene, and fluoranthene require a LAD (paragraph A11b). Hypothetically, the LAD might be for FURTHER EVALUATION by conducting bioassays, since there was moderate concern in relation to subparagraphs A8a and e.

118. Biological evaluation. Hypothetical elutriate toxicity values (Tables 4 and 5) require a LAD for *Cymatogaster* (paragraph A14c), *Neomysis*, *Cancer* and *Crassostrea* larvae (paragraph A14d). Hypothetically, the LAD might be that there are RESTRICTIONS REQUIRED by the bioassay results due to high concern in relation to subparagraphs A15a, b, and c

119. Mass loading assessment (Figure 6). Mass loading for each contaminant in the water column can be calculated from the water column chemical evaluation using chemical data for both filtered and unfiltered elutriate water samples. These calculations estimate the total amount of suspended solids and contaminants associated with them remaining in the water column during aquatic disposal operations. The percentage of total containment of

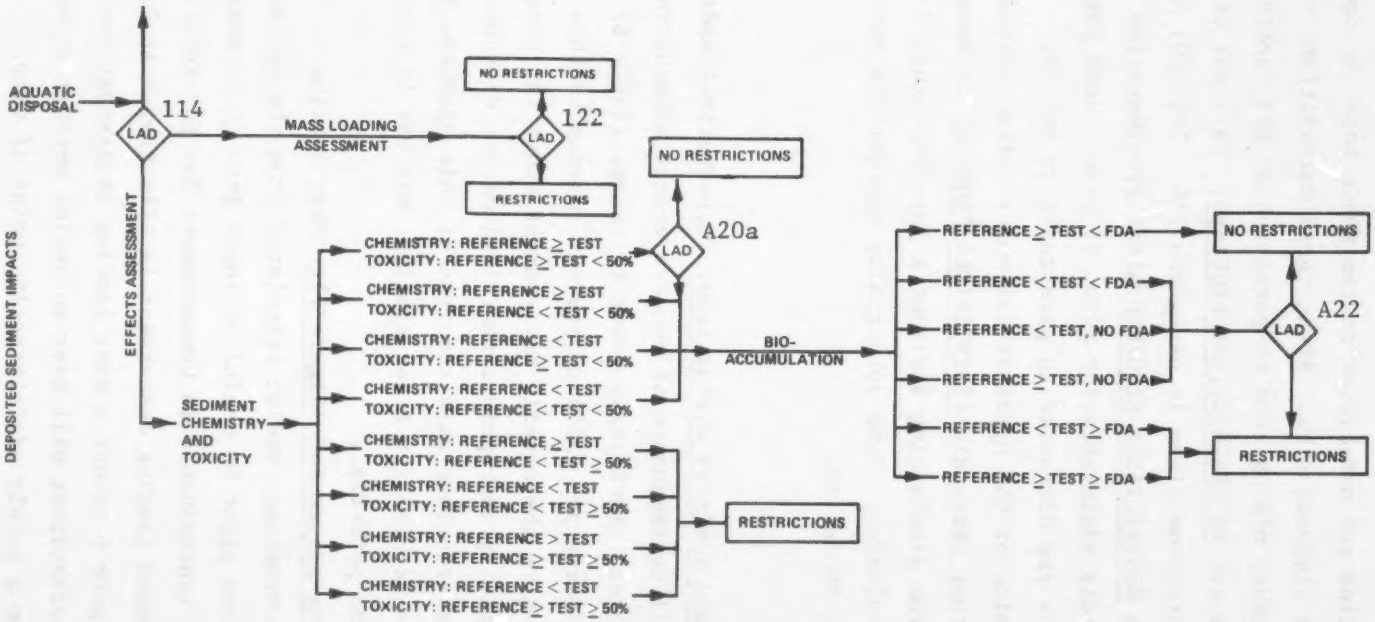
sediment and associated contaminants at the aquatic disposal site can then be calculated. In addition, dispersion models might be used to predict the spread of suspended solids and associated contaminants into the aquatic environment surrounding the disposal site. After these calculations are made and the factors discussed under mixing zone in paragraph 34 are considered, the LAD might be that there are NO RESTRICTIONS REQUIRED. This may be appropriate in light of the considerations given in paragraph 116. The LAD, however, might be that there are RESTRICTIONS REQUIRED after consideration of paragraph 116 or from a purely administrative point of view. Some potentially appropriate restrictions are discussed in paragraphs 75 and 76.

120. The conclusion of the hypothetical water column assessment of paragraphs 116-119 is that there are RESTRICTIONS REQUIRED to prevent adverse water column impacts from discharging sediment A into the aquatic environment under the conditions evaluated. Some potentially appropriate restrictions are described in paragraphs 79 and 76.

Benthic evaluation

121. Chemistry and toxicity evaluations. Hypothetical sediment chemistry values for all contaminants of concern except hexachlorobutadiene (Table 14) and hypothetical *Grandifoxus* toxicity values (Table 6) indicate RESTRICTIONS REQUIRED (paragraph A20f) to prevent adverse benthic impacts from discharging sediment A into the aquatic environment under the conditions evaluated. Some potentially appropriate restrictions are discussed in paragraphs 77-79. Since restrictions were required by this species, it was unnecessary to evaluate results for other species, nor was it necessary to evaluate bioaccumulation potential.

122. Mass loading assessment (Figure 7). Mass loading to the benthic environment for each contaminant can be calculated from the sediment chemistry data. These calculations might be useful as input into an inventory on the location and amount of contaminants in Commencement Bay for future reference. The implementation of mass loading assessment is illustrated in Figure 7, which is similar to Figure 6 except a mass loading assessment has been added. The Commencement Bay authorities will have to decide whether or not restrictions are required from a purely administrative point of view.


DEPOSITED SEDIMENT IMPACTS
AQUATIC DISPOSAL
LAD
114
MASS LOADING ASSESSMENT
LAD
122
NO RESTRICTIONS
RESTRICTIONS
EFFECTS ASSESSMENT
SEDIMENT CHEMISTRY AND TOXICITY
CHEMISTRY: REFERENCE ≥ TEST TOXICITY: REFERENCE ≥ TEST < 50%
CHEMISTRY: REFERENCE ≥ TEST TOXICITY: REFERENCE < TEST < 50%
CHEMISTRY: REFERENCE < TEST TOXICITY: REFERENCE ≥ TEST < 50%
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CHEMISTRY: REFERENCE > TEST TOXICITY: REFERENCE ≥ TEST ≥ 50%
CHEMISTRY: REFERENCE < TEST TOXICITY: REFERENCE ≥ TEST ≥ 50%
LAD
A20a
NO RESTRICTIONS
RESTRICTIONS
BIO-ACCUMULATION
REFERENCE ≥ TEST < FDA
REFERENCE < TEST < FDA
REFERENCE < TEST, NO FDA
REFERENCE ≥ TEST, NO FDA
REFERENCE < TEST ≥ FDA
REFERENCE ≥ TEST ≥ FDA
LAD
A22
NO RESTRICTIONS
RESTRICTIONS

Figure 7. Flowchart for decisionmaking for aquatic disposal benthic impacts with a mass loading assessment (number near LAD is paragraph discussing LAD)

Overall conclusion

123. The conclusion of the hypothetical assessment of aquatic disposal in paragraphs 114-122 is that there are RESTRICTIONS REQUIRED to prevent adverse water column impacts, and there are RESTRICTIONS REQUIRED to prevent adverse benthic impacts from discharging sediment A into the aquatic environment under the conditions evaluated.

Upland disposal- sediment A

Effluent evaluation

124. Chemical evaluations. Hypothetically, the LAD might be to conduct a chemistry-based evaluation of the potential for effluent impacts (paragraph B4) since water-quality criteria exist for all but two of the metals, which are the primary contaminants of concern in sediment A.

125. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical effluent test values (Table 12) for mercury do not require restrictions (paragraph B6b). Hypothetical results for cadmium, copper, zinc, and PCB require a LAD (paragraph B6e). Hypothetically, the LAD might be that there are RESTRICTIONS REQUIRED to prevent possible contaminant impacts of the effluent on the receiving water, due to high concern in relation to subparagraphs B8a, b, c, d, and e. Some potentially appropriate restrictions are discussed in paragraphs 81-93. Since restrictions were required by these test results, it is unnecessary to complete other effluent evaluations.

126. A tentative Commencement Bay area LAD is to also evaluate unfiltered effluent water quality (Figure 8). Since there are no water-quality criteria for unfiltered water, two evaluations are possible: a suspended solids bioassay and comparison to unfiltered reference water. A suspended solids bioassay might indicate potential contaminant impacts of effluent and surface runoff discharge from the upland disposal site. Comparison of test results should be made to a suspended solids bioassay of the reference sediment according to Figure 8. Discussion of the LADs for this figure are similar to that in paragraphs B12-B18.

127. Mass loading assessment (Figure 8). Mass loading for each contaminant in effluent discharge can be calculated from the modified elutriate test evaluation by using chemical data from an unfiltered modified elutriate

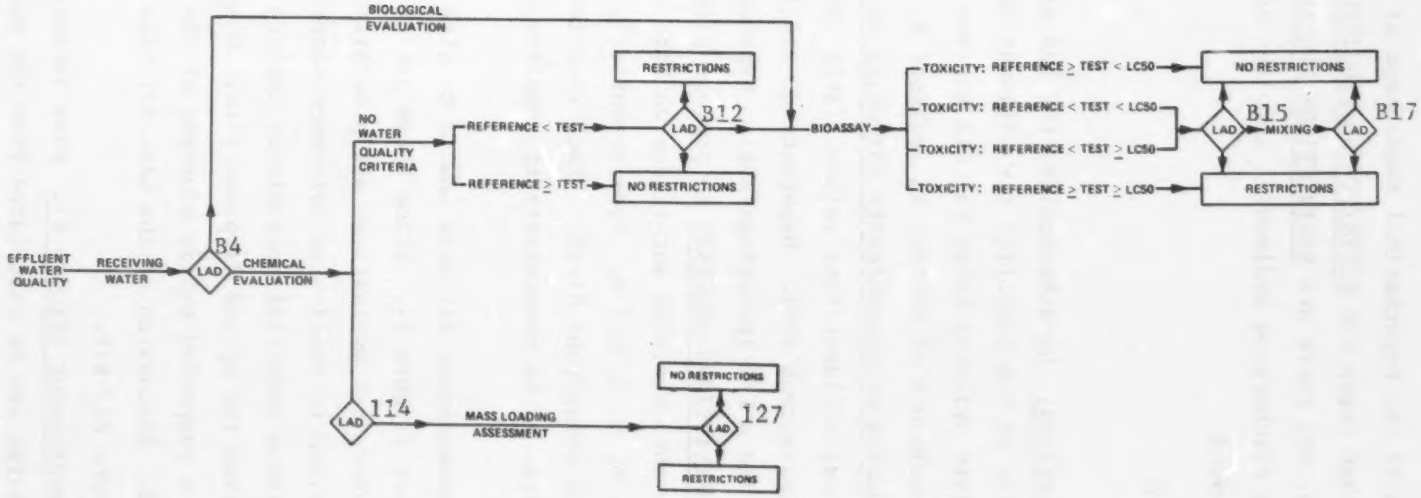
BIOLOGICAL EVALUATION
EFFLUENT WATER QUALITY
RECEIVING WATER
LAD
B4
CHEMICAL EVALUATION
NO WATER QUALITY CRITERIA
REFERENCE < TEST
REFERENCE ≥ TEST
RESTRICTIONS
LAD
B12
NO RESTRICTIONS
BIOASSAY
TOXICITY: REFERENCE ≥ TEST < LC50
TOXICITY: REFERENCE < TEST < LC50
TOXICITY: REFERENCE < TEST ≥ LC50
TOXICITY: REFERENCE ≥ TEST ≥ LC50
NO RESTRICTIONS
LAD
B15
MIXING
LAD
B17
RESTRICTIONS
LAD
114
MASS LOADING ASSESSMENT
NO RESTRICTIONS
LAD
127
RESTRICTIONS

Figure 8. Flowchart for decisionmaking for unfiltered effluent water quality with mass loading assessment (number near LAD is paragraph discussing LAD)

water sample. These calculations estimate the total amount of suspended solids and associated contaminants discharged into the receiving water during upland disposal operations. The percentage of total containment of dredged material and associated contaminants in the upland disposal site can then be calculated. In addition, dispersion models might be used to predict the potential spread of suspended solids and associated contaminants into the aquatic environment receiving the effluent discharge. After these calculations are made and the factors discussed under mixing zone in paragraphs 34 and 35 are considered, the LAD might be that there are NO RESTRICTIONS REQUIRED. This may be appropriate in light of the considerations given in paragraphs 34-35. The LAD, however, might be that there are RESTRICTIONS REQUIRED after consideration of paragraphs 34-35 or from a purely administrative point of view. This assessment was not necessary since restrictions were required in paragraph 125.

Surface runoff evaluation

128. Chemical evaluations. Hypothetically, the LAD might be to conduct a chemistry-based evaluation of the potential for surface runoff impacts (paragraph B19) since water-quality criteria exist for all but two of the metals, which are the primary contaminants of concern in sediment A.

129. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical surface runoff test values (Table 13) for cadmium, copper, mercury, zinc, and PCB require a LAD (paragraph B21e). Hypothetically, the LAD might be that there are RESTRICTIONS REQUIRED to prevent possible contaminant impacts of the surface runoff on the receiving water, due to high concern in relation to subparagraphs B23a, b, c, and e, and moderate concern in relation to subparagraph B23e. Some potentially appropriate restrictions are discussed in paragraphs 81-91 and 94. Since restrictions were required by these test results, it is unnecessary to complete other surface runoff evaluatons.

130. Mass loading assessment (Figure 9). Mass loading for each contaminant in surface runoff discharges can be calculated from the surface runoff test evaluation by using chemical data from an unfiltered runoff water sample. These calculations estimate the total amount of suspended solids and associated contaminants discharged into the receiving water during a storm

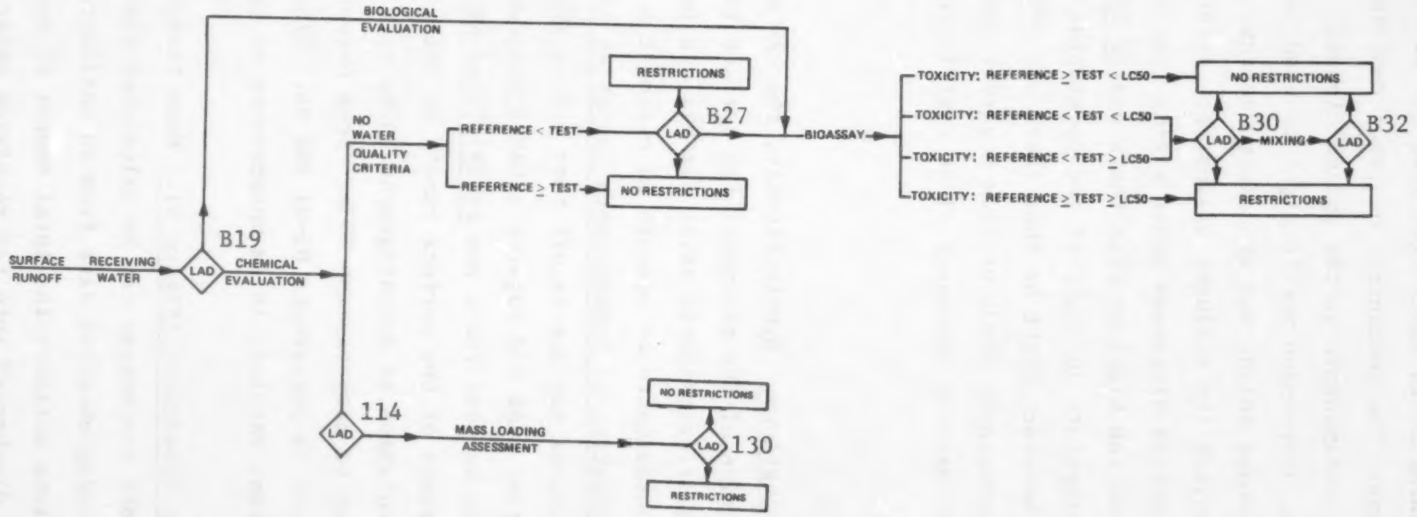
SURFACE RUNOFF
RECEIVING WATER
LAD
B19
CHEMICAL EVALUATION
BIOLOGICAL EVALUATION
NO WATER QUALITY CRITERIA
REFERENCE < TEST
REFERENCE ≥ TEST
RESTRICTIONS
NO RESTRICTIONS
LAD
B27
BIOASSAY
TOXICITY: REFERENCE ≥ TEST < LC50
TOXICITY: REFERENCE < TEST < LC50
TOXICITY: REFERENCE < TEST ≥ LC50
TOXICITY: REFERENCE ≥ TEST ≥ LC50
NO RESTRICTIONS
RESTRICTIONS
LAD
B30
MIXING
LAD
B32
LAD
114
MASS LOADING ASSESSMENT
LAD
130
NO RESTRICTIONS
RESTRICTIONS

Figure 9. Flowchart for decisionmaking for unfiltered surface runoff water quality with mass loading assessment (number near LAD is paragraph discussing LAD)

event at the upland disposal site. The percentage of total containment of dredged material and associated contaminants in the upland disposal site can then be calculated. In addition, dispersion models might be used to predict the potential spread of suspended solids and associated contaminants into the aquatic environment receiving the surface runoff discharge. After these calculations are made and the factors discussed under mixing zone in paragraphs 34 and 35 are considered, the LAD might be that there are NO RESTRICTIONS REQUIRED. This may be appropriate in light of the considerations given in paragraphs 34-35. The LAD, however, might be that there are RESTRICTIONS REQUIRED after consideration of paragraphs 34-35 or from a purely administrative point of view. This assessment was not necessary since restrictions were required in paragraph 129.

Leachate quality evaluation

131. The local authority may choose to consider leachate quality in relation to drinking water since the area is suspected of being a recharge area for a shallow aquifer (paragraph 102). A LAD might be to conduct a leachate test due to the unusually higher concentration of metals in sediment A than in the reference sediment. Hypothetical test results (Table 15) indicate leachate concentrations of arsenic, cadmium, copper, lead, and mercury from sediment A that exceed the reference water and drinking water standards and therefore lead to a DECISION FOR RESTRICTIONS (paragraph B51c). In the case of a nonpotable ground water, the LAD might consider potential water column impacts (Figure B5) by following the approach discussed in paragraphs 55-60.

Plant uptake evaluation

132. Hypothetically, the LAD might be that a DTPA extraction test is warranted (paragraph 62) due to the unusually high concentrations of metals in sediment A. Hypothetical test results (Table 16) indicate a potential for plant uptake of cadmium, copper, lead, mercury, and zinc (paragraph B63d). High concerns are indicated for paragraphs B65a, b, and c since these metals represent more than 25 percent of the metals of concern and all metals (especially cadmium and mercury, which are ranked 4 and 6) were greater than 10 times higher than reference values. These high concerns lead to a DECISION FOR FURTHER EVALUATION by conducting a plant bioassay (paragraphs 60 and 61).

133. Hypothetically, plant yield results (Table 17) lead to a LOCAL AUTHORITY DECISION (paragraph B66b). The LAD might be a DECISION FOR FURTHER EVALUATION by conducting a bioaccumulation evaluation (paragraph 61) is warranted. Bioaccumulation results (Table 17) indicate plant uptake of cadmium and zinc above demonstrated effect levels (Table C5) and cadmium above FDA-type levels (Table C8) which lead to a DECISION FOR RESTRICTIONS (paragraph B68d). The LAD could have been to require restrictions rather than conduct a bioaccumulation evaluation.

Animal uptake evaluation

134. Hypothetically, the LAD might be that an animal uptake/bioassay test is warranted (paragraph 65) due to the unusually high concentrations of metals in sediment A. Hypothetical test results of 98-percent toxicity (Table 18) and growth reductions (Table 19) lead to a DECISION FOR RESTRICTIONS (paragraph B74a) and no further testing required.

Human exposure evaluations

135. Hypothetically, concentrations of lead and mercury in sediment A (Table 14) exceed tabulated values for soil ingestion of lead and mercury (Tables C9 and C10) and therefore lead to a DECISION FOR RESTRICTIONS (paragraph B80b).

Nearshore disposal-sediment A

136. The foregoing test results and decisions for upland disposal will apply equally well to the nearshore disposal site. An additional aspect that needs to be considered is the leachate quality of dredged material placed in the saturated zone of the nearshore site (Table 20). Sediment A will be discussed in relationship to the previous paragraphs.

137. Restrictions would be required for effluent discharge (paragraphs 124-127). Restrictions will also be required for surface runoff (paragraphs 128-130). Leachates from the upland portions of the site will require restrictions (paragraph 131). Hypothetical test results of sediment A leachate from the saturated zone (Table 20) indicate As concentrations substantially greater than reference sediment concentrations and leads to a LOCAL AUTHORITY DECISION (paragraph B42b). The Commencement Bay area authorities

might choose to reach a DECISION FOR RESTRICTIONS due to sediment A leachate containing arsenic at a substantial margin above reference concentrations. Restrictions would be required for sediment A for plant uptake concerns (paragraphs 132 and 133), animal uptake (paragraph 134) and for human exposure (paragraph 135).

Example Interpretation of Results-Sediment B

Aquatic disposal-sediment B

Water column evaluation

138. Hypothetically, the LAD might be that site- and sediment-specific water column testing is warranted (paragraph A2).

139. Chemical evaluations. Hypothetically, a LAD might be that chemistry-based evaluations of the potential for water column impacts are inappropriate (paragraph A4), due to concern over possible interactive effects of the multiple contaminants of concern (particularly several organics) hypothetically present in sediment B (Table 14). Therefore, a biological evaluation would be appropriate.

140. Biological evaluations. Hypothetical elutriate toxicity values (Tables 4 and 5) require a LAD for *Cymatogaster, Neomysis, Cancer,* and *Crassostrea* larvae (paragraph A14c). Hypothetically, the LAD might be that there are RESTRICTIONS REQUIRED by the bioassay results due to high concern in relation to subparagraphs A16a, b, and c.

141. The conclusion of the hypothetical water column assessment of paragraphs 138-140 is that there are RESTRICTIONS REQUIRED to prevent adverse water column impacts from discharging sediment B into the aquatic environment under the conditions evaluated. Some potentially appropriate restrictions are described in paragraphs 75 and 76.

Benthic evaluation

142. Chemistry and toxicity evaluation. Hypothetical sediment chemistry values for all contaminants of concern (Table 14) and hypothetical *Pandalus, Macoma, Neanthes,* and *Parophrys* toxicity values (Table 7) and hypothetical *Grandifoxus* (Table 6) toxicity values require FURTHER EVALUATION by assessing the potential for bioaccumulation (paragraph A20c or d).

143. Bioaccumulation evaluation. Hypothetical contaminant concentration of arsenic, cadmium, and mercury in *Macoma* (Table 8), arsenic in *Pandalus* (Table 9), cadmium in *Neanthes* (Table 10), and arsenic, cadmium, and lead in *Parophrys* (Table 11) exceed FDA-type limits and indicate RESTRICTIONS REQUIRED (paragraph A21b) to prevent adverse benthic impacts from discharging sediment B into the aquatic environment under the conditions evaluated. Some potentially appropriate restrictions are discussed in paragraphs 75-80. In practice, the bioaccumulation assessment can be halted as soon as one contaminant-species combination gives results requiring restrictions; all were identified above for the sake of completeness for illustrative purposes.

Overall conclusion

144. The conclusion of the hypothetical assessment of aquatic disposal in paragraphs 138-143 is that there are RESTRICTIONS REQUIRED to prevent adverse water column impacts, and there are RESTRICTIONS REQUIRED to prevent adverse benthic impacts from discharging sediment B into the aquatic environment under the conditions evaluated.

Upland disposal- sediment B

Effluent evaluation

145. Chemical evaluation. Hypothetically, a LAD might be that chemistry-based evaluations of the potential for effluent impacts are inappropriate (paragraph B4) due to concern over possible interactive effects of multiple contaminants of concern (particularly several organic compounds) hypothetically present in sediment B (Table 14). Therefore, a biological evaluation would be appropriate.

146. Biological evaluation. Hypothetical effluent (modified elutriate) toxicity values (Table 21) require a LAD for *Cymatogaster*, *Neomysis*, *Cancer* larvae (paragraph B14c), and *Crassastrea* larvae (paragraph B14d). Hypothetically, the LAD might be for FURTHER EVALUATION by considering mixing, since there is high concern in relation to subparagraphs B16a and b, and only moderate concern in relation to subparagraphs B16c. When the mixing zone required to bring the discharge to less than the LC50 for *Crassostrea* (the species requiring the greatest dilution volume) at the upland disposal site is calculated (Appendix D, sediment B effluent mixing zone), it has the following characteristics:

a. Volume of 13 cu ft/sec dilution water required.

b. Surface area projection negligibly small.

c. Plume length and width negligibly small.

d. Intermittant discharge with storms after completion of the dredging and disposal operation.

e. No municipal water intakes in Commencement Bay.

f. No potential drinking water aquifers recharge from the waterway or Commencement Bay.

g. No human water contact activities in waterway, low activity in Commencement Bay.

h. Light recreational shell fishing along shore outside waterway about 3 miles away.

i. No fishing in waterway, year-round sport bottom fishing and seasonal drift netting of salmonids outside waterway about 3 miles away.

j. Nearest fish migration, spawning or nursery area outside waterway about 5 miles away; migration overlaps dredging by approximately 2 weeks.

k. Major sewage and industrial discharges and nonpoint industrial runoff into nearby waterway.

Hypothetically, the LAD might be that such a mixing zone is acceptable (paragraph B17a) in view of the considerations of paragraph 34, and thus restrictions are not required by the bioassay results.

147. The conclusion of the hypothetical effluent (modified elutriate) assessment of paragraphs 145 and 146 is that there are NO RESTRICTIONS REQUIRED to prevent adverse impacts from the effluent of sediment B placed in the upland disposal site.

Surface runoff evaluation

148. Chemical evaluations. Hypothetically, the LAD might be to conduct a chemistry-based evaluation of the potential for surface runoff impacts (paragraph B19).

149. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical surface runoff values (Table 13) for cadmium, mercury, and zinc do not require restrictions (paragraph B21b). The hypothetical surface runoff value for copper and PCB require a LAD (paragraph B21e). Hypothetically, the LAD might be for FURTHER EVALUATION by considering mixing due to high concern in relation to subparagraphs B23a and e, and moderate concern in relation to subparagraphs B23b, c, and d. When the mixing zone

required to dilute PCB (the contaminant of concern requiring the greatest dilution volume) in the discharge to the acute criterion at the upland disposal site (paragraphs 99-102) is calculated (Appendix D, sediment B surface runoff mixing zone), it has the following characteristics:

- a. Volume of 2,844 cu ft/sec dilution water required.
- b. Surface area projection negligibly small.
- c. Plume width 47 ft and length negligibly small.
- d. Intermittant discharge with storms after completion of the dredging and disposal operation.
- e. No municipal water intakes in Commencement Bay.
- f. No potential drinking water aquifers recharge from the waterway or Commencement Bay.
- g. No human water contact activities in waterway, low activity in Commencement Bay.
- h. Light recreational shell fishing along shore outside waterway about 3 miles away.
- i. No fishing in waterway, year-round sport bottom fishing and seasonal drift netting of salmonids outside waterway about 3 miles away.
- j. Nearest fish migration, spawning or nursery area outside waterway about 5 miles away; migration overlaps dredging by approximately 2 weeks.
- k. Major sewage and industrial discharges and nonpoint industrial runoff into nearby waterway.

Hypothetically, the LAD might be that such a mixing zone is acceptable (paragraph B25a) in view if the considerations of paragraph 34, and thus restrictions are not required by the results in relation to criteria.

150. Chemical evaluation of contaminants for which acute water-quality criteria do not exist. Hypothetical surface runoff values (Table 13) do not require restrictions for naphthalene, fluorene, phenanthrene, benzo(a)pyrene, hexachlorobutadiene, hexachlorobenzene, and pentachlorophenol (paragraph B26a). Hypothetical surface runoff values require a LAD for arsenic, lead, fluoranthene, and pyrene (paragraph B26b). Hypothetically, the LAD might be that restrictions are not required due to low concern in relation to subparagraphs B23a, c, and e. The conclusion of the hypothetical surface runoff assessments of paragraphs 148-150 is that there are NO RESTRICTIONS REQUIRED to prevent adverse impacts from the surface runoff of sediment B placed in the upland disposal site.

Leachate quality evaluation

151. The local authority may choose to consider leachate quality in relation to drinking water since the area is suspected of being a recharge area for a shallow aquifer (paragraph 102). A LAD might be to conduct a leachate test due to the higher concentrations of metals in sediment B than in the reference sediment. Hypothetical test results (Table 15) indicate leachate concentrations of metals are greater than reference ground water and equal to or less than drinking water standards and therefore lead to a LOCAL AUTHORITY DECISION (paragraph B51d). The local authority may choose to reach a DECISION FOR RESTRICTIONS due to leachate cadmium concentration being equal to the drinking water standard.

Plant uptake evaluation

152. Hypothetically, the LAD might be that a DTPA extraction test is warranted (paragraph 62) due to the higher concentration of metals in sediment B than in the reference sediment. Hypothetical test results (Table 16) indicate a potential for plant uptake of cadmium, copper, lead, and zinc (paragraph B63d). High concerns are indicated for paragraphs B65a, b, and c since these metals represent four out of six metals or 67 percent; these metals are more than 10 times reference and cadmium is ranked 4 in toxicological importance (Table C3). These high concerns lead to a DECISION FOR FURTHER EVALUATION by conducting a plant bioassay (paragraphs 60 and 61).

153. Hypothetically, plant yield results (Table 17) lead to a DECISION FOR FURTHER EVALUATIONS (paragraph B66a) by conducting a bioaccumulation evaluation. Bioaccumulation results (Table 17) lead to a LOCAL AUTHORITY DECISION (paragraph B681) and indicate high concern in two factors (paragraphs B70a and d). Plant content of arsenic, cadmium, and copper (three out of six metals or 50 percent) was above reference and cadmium is ranked 4 in toxicological importance (Table C3). Two high concerns in plant contents is sufficient to lead to a DECISION FOR RESTRICTIONS (paragraph B70a). In addition, if the Commence Bay area authorities desire to fully evaluate the potential for mass movement of contaminants into plants, total uptake could be considered. Total uptake results (Table 17) indicate high concern in two factors (paragraph B72a and c). Total uptake of arsenic, cadmium, and copper (three out of six metals or

50 percent) was greater than the reference. Cadmium is ranked 4 in toxicological importance (Table C3). Two high concerns lead to a DECISION FOR RESTRICTIONS (paragraph B72).

Animal uptake evaluation

154. Hypothetically, the LAD might be that an animal uptake/bioassay test is warranted (paragraph 65) due to the higher concentration of metals in sediment B than in the reference sediment. Hypothetical test results of 1-percent toxicity (Table 18) leads to a DECISION FOR FURTHER EVALUATION (paragraph B74b) by conducting a bioaccumulation evaluation. Bioaccumulation results (Table 19) indicate animal contents for arsenic, cadmium, copper, lead, and zinc that exceed FDA-type limits (Table C1) and therefore lead to a DECISION FOR RESTRICTIONS (paragraph B75b).

Human exposure evaluation

155. Hypothetically, concentrations of metals in sediment B (Table 14) are less than tabulated values for soil-ingested metals (Tables C9 and C10) and therefore lead to a DECISION OF NO RESTRICTIONS (paragraph B80a).

Nearshore disposal-sediment B

156. The foregoing test results and decisions for upland disposal will apply equally well to the nearshore disposal site. An additional aspect that needs to be considered is the leachate quality of dredged material placed in the saturated zone of the nearshore site (Table 20). Sediment B will be discussed in relationship to the previous paragraphs.

157. No restrictions would be required for effluent discharges (paragraphs 145-147). No restrictions would be required for surface runoff discharge (paragraphs 148-150). Leachate for the upland portion of the site will require restrictions (paragraph 151). Hypothetical test results (Table 20) of sediment B leachate from the saturated zone indicates PCB concentrations substantially above the chronic criteria. Therefore, these results lead to a LOCAL AUTHORITY DECISION (paragraph B37d). The Commence Bay area authorities might choose to reach a DECISION FOR RESTRICTIONS due to sediment B leachate containing PCBs at a substantial margin above the chronic criteria (Table 20). RESTRICTIONS would be required for plant uptake (paragraphs 152 and 153) and

for animal uptake (paragraph 154). There would be NO RESTRICTIONS required for human exposure concerns (paragraph 155).

Example Interpretation of Results-Sediment C

Aquatic disposal-sediment C

Water column evaluation

158. Hypothetically, a LAD might be that site- and sediment-specific water column testing is warranted (paragraph A2).

159. Chemical evaluation. Hypothetically, a LAD might be to conduct a chemistry-based evaluation of the potential for water column impacts (paragraph A4) since water-quality criteria exist for many of the contaminants of concern present in highest concentrations.

160. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical elutriate test values (Table 3) do not require restrictions for mercury (paragraph A6a), cadmium, copper, zinc, and PCB (paragraph A6e).

161. Chemical evaluation of contaminants for which acute water-quality criteria do not exist. Hypothetical elutriate test values (Table 3) for arsenic, naphthylene, fluorene, phenanthrene, fluoranthene, pyrene, benzo(a)pyrene, hexacholorbutaodiene, hexachlorobenzene, and pentachlorophenol do not require restrictions (paragraph A11a). The hypothetical elutriate value for lead requires a LAD (paragraph A11b). Hypothetically, the LAD might be that restrictions are not required since there was low concern in relation to subparagraphs A8a, b, and e.

162. Biological evaluation. Biology-based evaluations were not originally selected (paragraph A4), and were not indicated by test results (paragraph A12).

163. The conclusions of the hypothetical water column assessment of paragraphs 158-161 is that there are NO RESTRICTIONS REQUIRED to prevent adverse water column impacts from discharging sediment C into the aquatic environment under the conditions evaluated.

Benthic evaluation

164. Chemistry and toxicity evaluation. Hypothetical sediment chemistry values for all contaminants of concern (Table 14) and hypothetical *Pandalus*,

Macoma, *Neanthes*, and *Parophrys* toxicity values (Table 7) and hypothetical *Grandifoxus* toxicity values (Table 6) require FURTHER EVALUATION by assessing the potential for bioaccumulation (paragraph A20c or d).

165. Bioaccumulation evaluation. Hypothetical concentrations of most contaminants of concern in tissues of *Macoma*, *Pandalus*, *Neanthes*, and *Parophrys* (Tables 8-11) require a LAD (paragraph A21d or e). Hypothetically, the LAD might be that restrictions are required due to high concern in relation to subparagraphs A23a, b, c, d, e, f, j, and l. Some potentially appropriate restrictions are described in paragraphs 75-80.

Overall conclusion

166. The conclusion of the hypothetical assessment of aquatic disposal in paragraphs 158-165 is that there are NO RESTRICTIONS REQUIRED to prevent adverse water column impacts, and there are RESTRICTIONS REQUIRED to prevent adverse benthic impacts from discharging sediment C into the aquatic environment under the conditions evaluated.

Upland disposal-sediment C

Effluent evaluation

167. Chemical evaluation. Hypothetically, the LAD might be to conduct a chemistry-based evaluation of the potential for effluent impacts (paragraph B4) since water-quality criteria exist for many of the contaminants of concern present in the sediment in highest concentrations.

168. Chemical evaluation of contaminants for which acute water-quality criteria exist. Hypothetical effluent test values (Table 12) for cadmium and mercury (paragraph B6a) and zinc (paragraph B6b) do not require restrictions. Hypothetical effluent values require a LAD for copper and PCB (paragraph B6e). Hypothetically, the LAD might be for FURTHER EVALUATION by considering mixing due to moderate concern in relation to subparagraphs B8a, c, d, and e and low concern in relation to subparagraph B8b. When the mixing zone required to dilute PCB (the contaminant of concern requiring the greatest dilution volume) in the discharge to the acute criterion at the upland disposal site (paragraphs 101 and 102) is calculated (Appendix D, sediment c), it has the following characteristics:

a. Volume of 473 cu ft/sec dilution water required.

b. Surface area projection is negligibly small.

c. Plume 8 ft wide and of negligible length.

d. Intermittant discharge with storms after completion of the dredging and disposal operation.

e. No municipal water intakes in Commencement Bay.

f. No potential drinking water aquifers recharge from the waterway or Commencement Bay.

g. No human water contact activities in waterway, low activity in Commencement Bay.

h. Light recreational shell fishing along shore outside waterway about 3 miles away.

i. No fishing in waterway, year-round sport bottom fishing and seasonal drift netting of salmonids outside waterway about 3 miles away.

j. Nearest fish migration, spawning or nursery area outside waterway about 5 miles away; migration overlaps dredging by approximately 2 weeks.

k. Major sewage and industrial discharges and nonpoint industrial runoff into nearby waterway.

Hypothetically, the LAD might be that such a mixing zone is acceptable (paragraph B9a) in view of the considerations of paragraph 34, and thus restrictions are not required by the results in relation to criteria.

169. Chemical evaluation of contaminants for which acute water-quality criteria do not exist. Hypothetical effluent values (Table 12) for naphthalene, fluorene, phenanthrene, fluoranthene, pyrene, benzo(a)pyrene, hexachlorobutadiene, and hexachlorobenzene do not require restrictions (paragraph B11a). Hypothetical effluent values require a LAD for arsenic, lead, and pentachlorophenol (paragraph B11b). Hypothetically, the LAD might be for FURTHER EVALUATION by conducting bioassays due to moderate concern in relation to subparagraphs B8a and e and low concern in relation to subparagraph B8c.

170. Biological evaluation. Hypothetical effluent (modified elutriate) toxicity values *Neomysis* and *Crassostrea* (Table 21) do not require restrictions (paragraph B14a). Results for *Cancer* require a LAD (paragraph B14c).

171. The conclusion of the hypothetical effluent (modified elutriate) assessment of paragraphs 167-170 is that there are NO RESTRICTIONS REQUIRED to prevent adverse impacts from the effluent of sediment C placed in the upland disposal site.

Surface runoff evaluation

172. *Chemical evaluations.* Hypothetically, the LAD might be to conduct a chemistry-based evaluation of the potential for surface runoff impacts (paragraph B19).

173. *Chemical evaluation of contaminants for which acute water-quality criteria exist.* Hypothetical surface runoff values (Table 13) do not require restrictions for cadmium, mercury, PCB (paragraph B21a), copper and zinc (paragraph B21b).

174. *Chemical evaluation of contaminants for which acute water-quality criteria do not exist.* Hypothetical surface runoff values (Table 13) for arsenic, naphthalene, fluorene, phenanthrene, fluoranthene, pyrene, benzo(a)-pyrene, hexachlorobutadiene, hexachlorobenzene, and pentachlorophenol do not require restrictions (paragraph B26a). Hypothetical values require a LAD for lead (paragraph B26b). Hypothetically, the LAD might be that there are *NO RESTRICTIONS REQUIRED* due to low concern in relation to subparagraphs B23a and b.

Leachate quality evaluation

175. The local authority may choose to consider leachate quality in relation to potable ground water since the area is suspected of being a recharge area for a shallow aquifer (paragraph 102). A LAD might be to conduct a leachate test due to the higher concentrations of metals in sediment C than in the reference sediment. Hypothetical test results (Table 15) indicate leachate concentrations of metals are greater than reference ground water and less than drinking water standards and therefore lead to a *LOCAL AUTHORITY DECISION* (paragraph B51d). Leachate results indicate a high concern in one factor (paragraph B31) since four out of six metals or 67 percent exceeded reference. Only one metal (zinc) was 25 times reference representing a moderate concern but zinc is ranked 1 in toxicological importance and therefore is a low concern. Based on these results, the local authority may choose to reach a *DECISION FOR NO RESTRICTIONS.*

Plant uptake evaluations

176. Hypothetically, the LAD might be that a DTPA extraction test is warranted (paragraph 62) due to the higher concentrations of metals in sediment C than the reference sediment. Hypothetical test results (Table 16)

indicate a slight potential for plant uptake of cadmium, copper, lead, and zinc and leads to a DECISION FOR FURTHER EVALUATION (paragraph B63d). Hypothetically, plant yield results (Table 17) leads to a DECISION FOR FURTHER EVALUATION (paragraph B66a) by conducting the bioaccumulation evaluation (paragraph B68). Bioaccumulation results (Table 17) indicates all tissue concentration of contaminants of concern are equal to or less than the reference and demonstrated effects lead to a DECISION OF NO RESTRICTIONS (paragraph B68a). In addition, the Commence Bay area authorities should fully evaluate the potential for mass movement of contaminants into plants by considering total uptake, even though bioaccumulation was equal to or less than the reference. Total uptake of all contaminants of concern were less than that of the reference, which leads to a DECISION OF NO RESTRICTIONS.

Animal uptake evaluation

177. Hypothetically, the LAD might be that an animal uptake bioassay test is warranted (paragraph 65) due to the higher concentration of metals in sediment C than in the reference sediment. Hypothetical test results of 0 percent toxicity (Table 18) leads to a DECISION FOR FURTHER EVALUATION (paragraph B74b) by conducting a bioaccumulation evaluation. Bioaccumulation results (Table 19) indicate animal contents for arsenic, cadmium, and lead that exceed FDA-type limits (Table C1) and therefore lead to a DECISION FOR RESTRICTIONS (paragraph B75b).

Human exposure evaluation

178. Hypothetically, concentrations of metals in sediment C (Table 14) are less than tabulated values for soil-ingested metals (Table C9) and therefore lead to a DECISION OF NO RESTRICTIONS (paragraph B80a).

Nearshore disposal

179. The foregoing test results and decisions for upland disposal will apply equally well to the nearshore disposal site. An additional aspect that needs to be considered is the leachate quality of dredged material placed in the saturated zone of the nearshore site (Table 20). Each sediment will be discussed in relationship to the previous paragraphs.

180. NO RESTRICTIONS would be required for effluent discharge (paragraphs 167-171) or for surface runoff discharges (paragraphs 172-174).

NO RESTRICTIONS would be required for leachates from sediment C (paragraph 175) and based on the hypothetical test results in Table 20. These latter test results would generally lead to a DECISION OF NO RESTRICTIONS (paragraph B37a). However, a tentative Commencement Bay LAD would consider impacts of nonpotable ground water resurfacing and resulting in an accumulation of previously dissolved contaminants in surface sediments at the point of resurfacing (paragraph B59). Benthic impact tests on the original sediment C might be considered as the worst possible case for recontamination of surface sediments. Based on the benthic bioaccumulation tests described above, RESTRICTIONS would be required for leachate to protect against potential contaminant bioaccumulation in benthic organisms according to the above scenario. NO RESTRICTIONS would be required for plant uptake (paragraph 176). RESTRICTIONS on animal uptake would be required (paragraph 177). NO RESTRICTIONS would be required for human exposure (paragraph 178).

PART IV: SUMMARY

181. Parts I and II of this document describe appropriate types of tests and the evaluation and interpretation of test results. These parts can be applied to any dredged material. Part III is a hypothetical example of the application of Parts I and II to Commencement Bay, Washington, and is useful in conjunction with Parts I and II to illustrate the actual mechanism of the decisionmaking process.

182. All of the comparisons made in the example Part III were based on a reference sediment or reference water representative of pristine background areas of Puget Sound in accordance with the goal for returning Commencement Bay back to a cleaner environment. Consequently, more dredged material will be found to exceed reference values by substantially wider margins and thus restrictions will be required in more cases than if a less pristine reference site were chosen.

183. A summary of the decisions reached using the tentative Commencement Bay area LADs for disposal of sediments A, B, and C in aquatic, upland, and nearshore environments is presented in Table 22. The tentative decisions of Commencement Bay area authorities were to administratively establish numeral guidance for interpreting bioaccumulation and each of the LADs points in Figures 6-9, A1 and A2, and B1-B8. These decisions resulted in the need for restrictions on disposal of sediment A in each of the three disposal environments; sediment B required restrictions in both upland and nearshore disposal environments while only needing restrictions for the benthic portion of the aquatic disposal site (no restrictions were required for the water column portion); and sediment C required restrictions in the upland disposal environment for animal uptake and in the nearshore disposal environment for effluent water, leachate quality, and animal uptake, while only needing restrictions for the benthic portion of the aquatic disposal site. Hypothetical data were used for illustrating the actual implementation of the decisionmaking framework and should not be construed as factual. Actual data and test results for Commencement Bay sediments will no doubt give different conclusions than presented in this report.

PART V: RECOMMENDATIONS

184. This document has been a continuing evaluation since initiation and has been prepared on the basis of technically sound conceptual approaches. It requires a continuing thorough technical review, but it is suitable for initial use. Many of the issues evaluated require further consideration and possible refinement as the document is developed into a more final form. Examples of some of these issues are listed below:

- The appropriateness of developing additional quantitative guidance for acceptable contaminant concentrations in animal tissues from human health and biological impact perspectives should be examined. Initial bioaccumulation screening techniques based on partitioning theory should be incorporated where appropriate, and the potential for biomagnification should be considered in relation to both human health and environmental impacts. Evaluation of potential human health impacts based on FDA limits could be supplemented by a ranking of contaminants by their importance in mammalian toxicology, perhaps based on health tolerances and/or cancer risks. Assessment of potential biological impacts could be improved by tabulation of tissue contaminant concentrations in organisms from so-called "clean" sites worldwide and summarization of literature on biological effects associated with specific levels of tissue contamination.
- The framework at present considers only chemical contaminants impacts. The same conceptual approach could be expanded to provide guidance on evaluation of the potential impacts of traditional parameters such as chemical oxygen demand (COD), etc.
- Practical utility of the framework in interpreting all chemical evaluations is dependent upon, among other things, identification of a manageable number of contaminants of concern for each project. At present, identification of the appropriate contaminants remains largely a subjective matter. Additional guidance is needed for identifying appropriate contaminants of concern for a given project, perhaps considering such things as contaminants present, concentrations, toxicological importance, and bioavailability and mobility in the system in question.
- Contaminants of concern must be analyzed with sufficient sensitivity to provide quantitation at concentrations of regulatory concern. The merits of specifying detection limits on the basis of (a) criteria or standards, (b) ability to quantitate clean reference materials, (c) technical attainability, and (d) routine availability should be considered and discussed. Different detection limits may be appropriate for different purposes or for different matrices (i.e., water, sediment, tissue) with the same contaminant.
- Findings of ongoing research need to be incorporated into the decisionmaking framework. This would involve both quantitative

test results and new insights regarding interpretation and evaluation of data. Programs such as the CE Long-term Effects of Dredging Operations (LEDO) Research Program, CE/EPA Field Verification Program (FVP), EPA research on Exposure and Biological Effects of In-Place Pollutants, other EPA research, and programs of other Federal and State agencies, particularly in the Puget Sound area, will provide useful input to the decisionmaking framework. The process of incorporation of findings of ongoing research must continue throughout the useful life of the document to keep it current.

- Guidance on evaluating potential ground-water leachate should be reviewed and revised, if necessary, to ensure technical and regulatory compatability with the proposed new EPA ground-water classification system when it is finalized.
- The decisionmaking framework is dependent upon local authority decisions (LADs) whenever scientific understanding is insufficient to justify decisions on a technical basis alone. For this reason, quantitative guidance on reaching the LADs is difficult to provide and potentially controversial. Yet their importance necessitates the most complete and objective guidance possible. The guidance for making LADs needs to be made as complete, objective, and quantitative as possible.
- Performance of all the tests required even for site-acceptability testing could exceed the cost of dredging for some small projects. Yet these projects could involve highly contaminated sediments. An effective means of adequately assessing potential environmental impacts of small projects without imposing prohibitive economic burdens needs to be identified.
- The concept of tiered testing needs to be incorporated in the framework wherever possible. In this approach relatively simple procedures are used as screening tests, perhaps eliminating the need for more extensive testing. This could be part of a useful approach for small projects.
- In order to document that the decisionmaking framework is, in fact, providing the degree of environmental protection expected of it, it is necessary to monitor the actual effects of discharge decisions reached by using the framework. These monitoring requirements and the interpretive guidance for evaluating the results will be generally similar to the testing and evaluation guidance in the decisionmaking framework. Monitoring and evaluative guidance needs to be clearly described in an orderly fashion.
- Although both aquatic and upland disposal operations can be designed and conducted so as to minimize loss of suspended particulates, it is inevitable that some particulate matter will leave the site. These particulates might conceptually be of concern if they were transported to and accumulated in appropriate areas such as beaches, spawning beds, etc.; if they concentrated contaminants to unacceptable levels in a depositional area away from the disposal site; or if there was a

potential for particle-associated contaminants to impact the water column as they were being dispersed. Attention should be given to evaluation of the potential for impact by these routes.

- The decisionmaking framework should be modified in the future as appropriate based on scientific and administrative experience with using it. The document has received technical review, and additional technical review at successive stages of its development is necessary. In addition, it should be used, perhaps in a dry-run sense, to evaluate several projects in order to identify problem areas and indicate potential improvements. The decisionmaking framework is intended to provide a useful first step with the full knowledge of the need for further technical and administrative refinement prior to actual implementation.

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Table 1

Relative Time and Cost Estimates for Conducting Test Protocols

Test Protocol	Time months	Cost/ Test Run* dollars	Number of Test Samples Analyzed	Cost of Chemical Analysis** dollars	Total Cost dollars
Dissolved chemical analysis and mixing	2	100	6	6,000- 9,000	6,100- 9,100
Water column bioassay and mixing	3	1,000-5,000	16		1,000- 5,000
Sediment comparison	2	100	8	8,000-12,000	8,100- 12,100
Benthic bioassay and bioaccumulation††	5	1,000-5,000	16	16,000-24,000	17,000- 29,000
Effluent quality	2	80	6	6,000- 9,000	6,080- 9,080
Runoff	6	4,000	15	15,000-22,500	19,000- 26,500
Leachate‡	12	25,000	50	50,000-75,000	75,000-100,000
Plant uptake‡‡	4	5,000	12	12,000-18,000	17,000- 23,000
Animal uptake§	4	4,000	12	12,000-18,000	16,000- 22,000

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* One sediment sample.

** Estimated cost for PCBs, pesticides, 10 metals, and suspended solids per analyzed sample ranged from $1,000 to $1,500.

† Does not include cost of equipment or facilities or sample collection and transport to lab.

†† Four species were used.

‡ Leaching test and serial batch tests are currently under development. Routine test cost will be lower.

‡‡ Plant bioassay of 45-day exposure.

§ Earthworm bioassay of 28-day exposure.

Table 2

Detection Limits for a Preliminary List of Contaminants of Potential Concern in Commencement Bay*

Contaminants	Sediment mg/kg	Plant mg/kg	Animal mg/kg	Water µg/ℓ
Metals				
Ag	0.1	0.1	0.1	0.6
As	0.1	0.05	0.1	1
Be	0.5	0.5	0.5	5
Cd	0.01	0.01	0.01	0.1
Cr	0.1	0.05	0.1	1
Cu	0.1	0.1	0.1	1
Hg	0.1	0.1	0.1	0.2
Ni	0.3	0.05	0.3	3
Pb	0.1	0.1	0.1	0.1
Sb	0.5	0.5	0.5	5
Se	0.2	0.05	0.2	2
Tl	0.1	0.1	0.1	1
Zn	0.1	0.1	0.1	1
Volatiles				
Benzene**	0.050	NA††	NA	10
Bromoform	↓	↓	↓	↓
Carbon tetrachloride				
Chloroform				
Chloroethane				
Chlorodibromomethane				
Dichloromethane				
Dichlorobromomethane				
Ethylbenzene**				
Formaldehyde†				
Tetrachloroethane**				
1,1,1-Trichloroethylene				
Toluene				
1,1-Dichloroethane				
1,1-Dichloroethylene†				
1,2-trans-Dichloroethylene†				
Xylene**				
Base/Neutrals (except PCBs)				
Haloginated compounds				
Hexachloroethane	0.2	0.2	0.2	10
1,2-Dichlorobenzene	0.2	0.2	0.2	10
1,3-Dichlorobenzene	0.2	0.2	0.2	10

(Continued)

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* Priority pollutants and other significant substances detected in Commencement Bay sediments, waters, or point sources.

** Reported in waters but not in sediments (to date).

† Reported only in point sources.

†† NA - Not applicable.

(Sheet 1 of 3)

Table 2 (Continued)

Contaminants	Sediment mg/kg	Plant mg/kg	Animal mg/kg	Water μg/ℓ
Base/Neutrals				
Haloginated compounds (Continued)				
1,4-Dichlorobenzene	0.2	0.2	0.2	10
1,2,4-Trichlorobenzene	↓	↓	↓	↓
2-Chloronaphthalene	↓	↓	↓	↓
Hexachlorobenzene	↓	↓	↓	↓
Hexachlorobutadiene	↓	↓	↓	↓
Misc. chlorinated butadienes**	↓	↓	↓	↓
Bis(2-chloroethyoxy) ether	↓	↓	↓	↓
Bis(2-chloroethyoxy) methane	↓	↓	↓	↓
Low molecular weight aromatics				
Azobenzene	0.2	0.2	0.2	10
Naphthalene	↓	↓	↓	↓
2-methylnaphthalene**	↓	↓	↓	↓
1-methylnaphthalene**	↓	↓	↓	↓
2,6-dimethylnaphthalene**	↓	↓	↓	↓
1,3-dimethylnaphthalene**	↓	↓	↓	↓
2,3-dimethylnaphthalene**	↓	↓	↓	↓
2,3,6-trimethylnaphthalene**	↓	↓	↓	↓
2,3,5-trimethylnaphthalene**	↓	↓	↓	↓
Acenaphthene	↓	↓	↓	↓
Acenaphthalene	↓	↓	↓	↓
Fluorene	↓	↓	↓	↓
Biphenyl**	↓	↓	↓	↓
Anthracene/phenanthrene	↓	↓	↓	↓
1-methylphenanthrene**	↓	↓	↓	↓
2-methylphenanthrene**	↓	↓	↓	↓
High molecular weight aromatics				
Fluoranthene	0.2	0.2	0.2	10
Pyrene	↓	↓	↓	↓
1-methylpyrene**	↓	↓	↓	↓
Benzo(a)anthracene	↓	↓	↓	↓
Chrysene/triphenylene	↓	↓	↓	↓
Dibenzo(a,h)anthracene	0.5	0.5	0.5	25
Benzofluoranthenes	0.2	0.2	0.2	10
Benzo(e)pyrene**	0.2	0.2	0.2	10
Benzo(a)pyrene	0.2	0.2	0.2	10
Indeno(1,2,3-cd)pyrene	0.5	0.5	0.5	25
Benzo(g,h,i)perylene	0.5	0.5	0.5	25
Phthalate esters				
Diethylphthalate	0.2	0.2	0.2	10
Bis(2-ethylhexyl)phthalate	0.2	0.2	0.2	10

(Continued)

** Reported in waters but not in sediments (to date).

(Sheet 2 of 3)

Table 2 (Concluded)

Contaminants	Sediment mg/kg	Plant mg/kg	Animal mg/kg	Water μg/ℓ
Base/Neutrals				
Phthalate esters (Continued)				
Butylbenzylphthalate	0.2	0.2	0.2	10
Di-n-butylphthalate	↓	↓	↓	↓
Di-me-phthalate	↓	↓	↓	↓
Di-n-octylphthalate	↓	↓	↓	↓
Acid Extractables				
Cresol**	0.5	0.5	0.5	25
Phenol	↓	↓	↓	↓
2-chlorophenol	↓	↓	↓	↓
2,4-dichlorophenol†	↓	↓	↓	↓
2,4,6-trichlorophenol	↓	↓	↓	↓
Pentachlorophenol	↓	↓	↓	↓
P-chloro-m-cresol	↓	↓	↓	↓
4-nitrophenol	↓	↓	↓	↓
Pesticides and PCBs				
A-chlordane	1	0.001	0.001	0.001
Aldrin	0.2	0.0002	0.0002	0.010
α-Hexachlorocyclohexane (HCH)††	↓	↓	↓	↓
β-HCH	↓	↓	↓	↓
γ-HCH (lindane)	↓	↓	↓	↓
4-4'-DDD	↓	↓	↓	↓
4,4'-DDE	↓	↓	↓	↓
4,4'-DDT	↓	↓	↓	↓
PCB-1242	2	0.002	0.002	0.01
PCB-1248	2	0.002	0.002	0.01
PCB-1254	2	0.002	0.002	0.01
PCB-1260	4	0.004	0.004	0.02
Miscellaneous substances				
Manganese (Mn)†	0.1	0.1	0.1	0.001
Molybdenum (Mo)†	0.1	0.0001	0.0001	0.001
A-endosulfan†	0.2	0.0002	0.0002	0.004
Cyanide†	1	1.0	1.0	1
Nitrosodiphenylamine	0.2	0.2	0.2	0.010

** Reported only in point sources.

† Reported in waters but not in sediments (to date).

†† Hexachlorocyclohexanc (HCH) is sometimes referred to elsewhere as BHC (benzene hexachloride), but this is a misnomer and is not used here.

(Sheet 3 of 3)

Table 3

Hypothetical Example of Concentrations of Dissolved Contaminants in Standard Elutriates of Three Puget Sound Sediments

Contaminants of Concern	Acute Criterion-Saltwater	Reference Site Water	Sediment		
			A	B	C
As	--*	10.0	35	27	5
Cd	59	0.2	1.2	0.9	0.3
Cu	23	1.1	10	2.3	1.2
Pb	--	2.2	8	9.1	3.1
Hg	3.7	0.01	0.03	0.02	0.01
Zn	170	12.8	32	16.7	13
Base/neutrals					
Naphthalene	--	<1	3	2	<1
Fluorene	--	<1	3	2	<1
Phenanthrene	--	<1	2	1	<1
Fluoranthene	--	<1	1	<1	<1
Pyrene	--	<1	<1	<1	<1
Benzo(a)pyrene	--	<1	<1	<1	<1
Hexachlorobutadiene	--	<1	<1	<1	<1
Hexachlorobenzene	--	<1	<1	<1	<1
Acid extractable					
Pentachlorophenol	--	<1	<1	<1	<1
Pesticides					
PCB (total)	0.030	0.005	0.04	0.03	0.02

Note: Values are in μg/ℓ.

* -- denotes criterion not established.

Table 4

Hypothetical Example of Toxicity of Elutriates of Three Puget Sound Sediments

Species	Treatment	Sediment A	Sediment B	Sediment C
Surf perch (*Cymatogaster aggregata* juveniles)	Control	0	0	0
	Reference site water	0	0	0
	10% elutriate	0	3	0
	50% elutriate	3	3	0
	100% elutriate	10	7	0
Mysid shrimp (*Neomysis americanus*)	Control	0	0	0
	Reference site water	0	3	0
	10% elutriate	10	3	0
	50% elutriate	55*	7	3
	100% elutriate	72	12	0
Dungeness crab (*Cancer magister* larvae)	Control	3	0	0
	Reference site water	7	0	3
	10% elutriate	7	0	3
	50% elutriate	42	18	7
	100% elutriate	81**	42	15

Note: Each treatment consisted of three replicates of 10 animals each. Values are mean percent mortality after 96 hr.

* 96-hr LC50 is 45 percent elutriate.

** 96-hr LC50 is 58 percent elutriate.

Table 5

Hypothetical Example of Toxicity of Elutriates of Three Puget Sound Sediments to Oyster Larvae (*Crassostrea gigas*)

Treatment	Sediment A	Sediment B	Sediment C
Control	0.5	2.9	2.0
Reference site water	4.7	5.8	3.2
10% elutriate	5.3	2.4	2.1
50% elutriate	32.9*	21.6	7.2
100% elutriate	69.6	39.0	21.3

Note: Values are mean percent abnormal larvae from two replicates per treatment after 48 hr.

* 48-hr EC50 for abnormality is 65 percent elutriate.

Table 6

Hypothetical Example of Toxicity of Deposits of Four Puget Sound Sediments to Amphipods *Grandifoxus grandis*

Treatment	Sediment			
	Reference	A	B	C
Control	0	0	0	0
Exposed	6	96	32	14

Note: Each treatment consisted of five replicates of 10 animals each. Values are mean percent mortality after 96 hr.

Table 7

Hypothetical Example of Toxicity of Deposits of Four Puget Sound Sediments to Four Benthic or Epibenthic Species

Species	Treatment	Sediment			
		Reference	A	B	C
Pandalus borealis	Control	0	0	0	1
	Exposed	0	15	5	0
Macoma balthica	Control	0	0	0	0
	Exposed	0	2	3	0
Neanthes arenaceodentata	Control	0	1	2	0
	Exposed	0	18	6	0
Parophrys vetulus (juvenile)	Control	0	0	0	0
	Exposed	1	2	1	0

Note: Each treatment consisted of five replicates of 20 animals each. Values are mean percent mortality after 10 days.

Table 8

Hypothetical Example of Contaminant Concentrations in Tissues of the Clam *Macoma balthica* Exposed to Deposits of Four Puget Sound Sediments for 30 Days

Contaminants of Concern	FDA Level*	Sediment			
		Reference	A	B	C
As	1.0	0.230	23.37	8.87	0.317
Cd	1.0	0.062	2.38	1.68	0.21
Cu	70	1.11	7.77	3.11	0.95
Pb	2.5	0.683	12.99	1.37	0.748
Hg	0.5	0.478	7.10	0.79	0.281
Zn	150	16.67	26.26	18.71	17.31
Base/neutrals					
Naphthalene	--**	0.01	0.007	0.024	0.014
Fluorene	--	0.0003	0.011	0.014	0.083
Phenanthrene	--	0.0002	0.010	0.014	0.082
Fluoranthene	--	0.0005	0.010	0.015	0.080
Pyrene	--	0.001	0.010	0.014	0.088
Benzo(a)pyrene	--	0.0001	0.013	0.009	0.005
Hexachlorobutadiene	--	0.004	0.001	0.038	0.025
Hexachlorobenzene	--	0.008	0.046	0.070	0.024
Acid extractable					
Pentachlorophenol	--	0.001	0.006	0.008	0.014
Pesticides					
PCB (total)	2.0	0.004	0.010	0.146	0.150

Note: Data are in µg/g on a whole body, wet weight basis.

* From Table C1.

** -- denotes no value established.

Table 9

Hypothetical Example of Contaminant Concentrations in Tissues of the Shrimp *Pandalus borealis* Exposed to Deposits of Four Puget Sound Sediments for 30 Days

Contaminants of Concern	FDA Level*	Sediment			
		Reference	A	B	C
As	1.0	0.71	8.62	1.63	0.27
Cd	--**	0.350	2.38	0.165	0.017
Cu	10	8.76	23.5	4.76	2.67
Pb	1.5	0.798	6.42	0.619	0.581
Hg	0.5	0.023	2.47	0.038	0.035
Zn	150	10.09	9.41	9.99	11.27
Base/neutrals					
Naphthalene	--	0.003	0.013	0.046	0.088
Fluorene	--	0.001	0.021	0.027	0.047
Phenanthrene	--	0.0007	0.020	0.026	0.050
Fluoranthene	--	0.001	0.020	0.029	0.057
Pyrene	--	0.0001	0.025	0.021	0.040
Benzo(a)pyrene	--	0.0002	0.025	0.020	0.041
Hexachlorobutadiene	--	0.008	0.002	0.073	0.048
Hexachlorobenzene	--	0.16	0.088	0.132	0.046
Acid extractable					
Pentachlorophenol	--	0.003	0.008	0.015	0.026
Pesticides					
PCB (total)	2.0	0.008	0.020	0.277	0.285

Note: Data are in μg/g on a whole body, wet weight basis.

* From Table C1.

** -- denotes no value established.

Table 10

Hypothetical Example of Contaminant Concentrations in Tissues of the Polychaete Worm *Neanthes arenaceodentata* Exposed to Deposits of Four Puget Sound Sediments for 30 Days

Contaminants of Concern	FDA Level*	Sediment			
		Reference	A	B	C
As	1.0	0.373	15.84	0.99	0.208
Cd	0.2	0.45	6.42	0.78	0.18
Cu	10	7.82	25.37	5.65	9.07
Pb	1.5	0.62	13.27	0.97	0.96
Hg	0.5	0.12	2.61	0.387	0.019
Zn	150	6.58	18.63	5.62	9.94
Base/neutrals					
Naphthalene	--**	0.006	0.009	0.030	0.017
Fluorene	--	0.0005	0.014	0.018	0.031
Phenanthrene	--	0.0005	0.013	0.017	0.030
Fluoranthene	--	0.001	0.012	0.018	0.031
Pyrene	--	0.001	0.013	0.020	0.37
Benzo(a)pyrene	--	0.0002	0.015	0.030	0.022
Hexachlorobutadiene	--	0.006	0.001	0.048	0.031
Hexachlorobenzene	--	0.010	0.058	0.097	0.030
Acid extractable					
Pentachlorophenol	--	0.002	0.002	0.015	0.058
Pesticides					
PCB (total)	2.0	0.005	0.013	0.182	0.018

Note: Data are in μg/g on a whole body, wet weight basis.

* From Table C1. See paragraph 26 for rationale for using these values with a nonfood type of organism.

** -- denotes no value established.

Table 11

Hypothetical Example of Contaminant Concentrations in Tissues of the Juvenile English Sole *Parophrys vetulus* Exposed to Deposits of Four Puget Sound Sediments for 30 Days

Contaminants of Concern	FDA Level*	Sediment			
		Reference	A	B	C
As	1.0	0.12	14.47	3.53	0.12
Cd	0.2	0.026	7.81	1.98	0.07
Cu	10	1.89	8.76	1.68	5.93
Pb	1.5	0.086	18.16	1.83	1.15
Hg	1.0	0.008	2.1	0.010	0.003
Zn	150	6.55	12.54	5.26	7.02
Base/neutrals					
Naphthalene	--**	0.003	0.018	0.061	0.035
Fluorene	--	0.001	0.027	0.036	0.062
Phenanthrene	--	0.0007	0.028	0.038	0.060
Fluoranthene	--	0.001	0.025	0.037	0.050
Pyrene	--	0.0005	0.030	0.020	0.060
Benzo(a)pyrene	--	0.001	0.031	0.020	0.062
Hexachlorobutadiene	--	0.011	0.003	0.096	0.063
Hexachlorobenzene	--	0.021	0.116	0.174	0.060
Acid extractable					
Pentachlorophenol	--	0.001	0.003	0.010	0.002
Pesticides					
PCB (total)	2.0	0.010	0.26	0.364	0.375

Note: Data are in μg/g on a whole body, wet weight basis.

* From Table C1.

** -- denotes no value established.

Table 12

Hypothetical Example of Concentrations of Dissolved Contaminants in Effluents of Confined Disposal Areas Containing Three Puget Sound Sediments

Contaminants of Concern	Acute Criterion-Saltwater	Reference Site Water	Sediment		
			A	B	C
As	--*	3.2	525	70	25
Cd	59	1.6	180	80	1.5
Cu	23	2.1	1,800	120	28
Pb	--	1.5	380	12	6
Hg	3.7	<0.1	1.4	0.2	<0.1
Zn	170	10	2,000	130	42
Base/neutrals					
Naphthalene	--	<1	12	12	<1
Fluorene	--	<1	11	<1	<1
Phenanthrene	--	<1	<1	11	<1
Fluoranthene	--	<1	<1	<1	<1
Pyrene	--	<1	<1	11	<1
Benzo(a)pyrene	--	<1	<1	<1	<1
Hexachlorobutadiene	--	<1	<1	<1	<1
Hexachlorobenzene	--	<1	11	10	<1
Acid extractable					
Pentachlorophenol	--	<1	<1	<1	12
Pesticides					
PCB (total)	0.030	0.01	0.05	0.87	0.48

Note: Values are in μg/ℓ.
* -- denotes criterion not established.

Table 13

Hypothetical Example of Concentrations of Dissolved Contaminants in Surface Water Runoff of Confined Disposal Areas Containing Three Puget Sound Sediments

Contaminants of Concern	Acute Criterion-Saltwater	Reference Site Water	Sediment		
			A	B	C
As	--*	3.2	40	5	2
Cd	59	1.6	110	4	1
Cu	23	2.1	300	50	8
Pb	--	1.5	108	20	5
Hg	3.7	<0.1	10	1	<0.1
Zn	170	10	250	100	60
Base/neutrals					
Naphthalene	--	<1	<1	<1	<1
Fluorene	--	<1	<1	<1	<1
Phenanthrene	--	<1	<1	<1	<1
Fluoranthene	--	<1	<1	1	<1
Pyrene	--	<1	<1	1	<1
Benzo(a)pyrene	--	<1	<1	<1	<1
Hexachlorobutadiene	--	<1	<1	<1	<1
Hexachlorobenzene	--	<1	<1	<1	<1
Acid extractable					
Pentachlorophenol	--	<1	<1	<1	<1
Pesticides					
PCB (total)	0.030	0.01	0.05	0.5	<0.01

Note: Soil surface was dried to typical field moisture content prior to tests. Values are in µg/ℓ.

* -- denotes criterion not established.

Table 14

Hypothetical Example of Total or Bulk Contaminant Concentrations in Four Puget Sound Sediments

Contaminants of Concern	Sediment			
	Reference	A	B	C
As	5.5	9,700	90.0	14.0
Cd	0.24	184	3.6	1.6
Cu	54.0	11,400	239.0	115.0
Pb	10.0	6,250	181.0	81.0
Hg	0.10	52	0.50	0.18
Zn	50.8	3,320	242.0	107.0
Base/neutrals				
Naphthalene	0.029	0.540	1.012	0.350
Fluorene	0.007	0.835	0.600	0.625
Phenanthrene	0.070	0.760	1.210	0.600
Fluoranthene	0.030	0.870	12.250	1.500
Pyrene	0.065	1.350	8.800	0.150
Benzo(a)pyrene	0.060	1.050	6.190	0.190
Hexachlorobutadiene	0.029	0.025	0.480	0.180
Hexachlorobenzene	0.065	1.280	1.050	0.220
Acid extractable				
Pentachlorophenol	0.030	0.100	0.100	0.350
Pesticides				
PCB (total)	0.025	0.260	2.000	1.245
Sand, percent	30.0	66.7	20.2	38.7
Silt, percent	40.0	25.2	54.7	42.3
Clay, percent	30.0	7.8	25.1	19.0
TOC, percent	2.5	8.8	4.4	2.9

Note: Values in mg/kg dry weight, except as otherwise indicated.

Table 15

Hypothetical Example of Concentrations of Dissolved Contaminants in Leachate of Confined Disposal Areas Containing Three Puget Sound Sediments

Contaminants of Concern	Chronic Criterion-Saltwater*	Drinking Water Standard**	Reference Water	Sediment		
				A	B	C
As	--†	50	2	120	12	6
Cd	4.5	10	1	500	10	4
Cu	4.0	1,000	17	2,000	82	41
Pb	--	50	1.0	500	2.0	1.4
Hg	0.025	2	0.1	7.0	0.7	0.3
Zn	58	5,000	10	1,500	625	250
Base/neutrals						
Naphthalene	--	--	<1	<1	12	<1
Fluorene	--	--	<1	<1	<1	<1
Phenanthrene	--	--	<1	<1	11	<1
Fluoranthene	--	--	<1	<1	15	12
Pyrene	--	--	<1	<1	11	<1
Benzo(a)pyrene	--	--	<1	<1	11	<1
Hexachlorobutadiene	--	--	<1	<1	<1	<1
Hexachlorobenzene	--	--	<1	<1	<1	<1
Acid extractable						
Pentachlorophenol	--	--	<1	<1	<1	<1
Pesticides						
PCB (total)	0.03	--	0.05	0.05	0.50	0.25

Note: Values are in μg/ℓ.
* Table C2.
** Table C4.
† --denotes value not established.

Table 16

Hypothetical Example of DTPA-Extractable Metals from Four Puget Sound Sediments

Contaminants of Concern	Sediment							
	Reference		A		B		C	
	Saturated	Dried	Saturated	Dried	Saturated	Dried	Saturated	Dried
Cd	0.0024	0.0030	0.001	51.0	<0.0005	1.51	0.0020	0.012
Cu	<0.025	0.67	0.05	71.2	0.04	39.6	<0.025	2.41
Pb	0.001	0.0012	0.91	388	9.71	73.4	0.72	2.01
Hg	<0.001	0.001	0.001	1.20	0.0010	0.0019	<0.001	0.0014
Zn	0.05	5.8	0.10	954	0.31	126	0.24	11.2

Table 17

Hypothetical Example of Plant Growth, Tissue Content, and Total Uptake of Contaminants for Yellow Nutsedge, *Cyperus esculentus*, Grown in Four Puget Sound Sediments

Contaminants of Concern	Effect Level*	Sediment											
		Reference			A			B			C		
		Yield	Content	Uptake	Yield	Content	Uptake	Yield	Content	Uptake	Yield	Content	Uptake
Growth		46			14			43			67		
As	--		0.041	2		1.45	20		0.38	16		0.030	2
Cd	8		1.05	48		21.05	295		5.32	229		0.71	47
Cu	20		2.54	117		9.51	133		4.41	203		1.70	113
Pb	--		1.58	73		4.10	57		1.80	77		1.05	70
Hg	--		0.010	0.5		0.90	13		0.016	0.7		0.008	0.5
Zn	200		81.0	3,726		290	4,060		90	3,870		54.1	3,625
Base/neutrals													
Naphthalene	--		<0.08	<4		<0.08	<1		<0.08	<3		<0.08	<5
Fluorene	--		<0.08	<4		<0.08	<1		<0.08	<3		<0.08	<5
Phenanthrene	--		<0.08	<4		<0.08	<1		<0.08	<3		<0.08	<5
Fluoranthene	--		<0.08	<4		<0.08	<1		<0.08	<3		<0.08	<5
Pyrene	--		<0.08	<4		<0.08	<1		<0.08	<3		<0.08	<5
Benzo(a)pyrene	--		<0.08	<4		<0.08	<1		<0.08	<3		<0.08	<5
Hexachlorobutadiene	--		<0.08	<4		<0.08	<1		<0.08	<3		<0.08	<5
Hexachlorobenzene	--		<0.08	<4		<0.08	<1		<0.08	<3		<0.08	<5
Acid extractable													
Pentachlorophenol	--		<0.08	<4		<0.08	<1		<0.08	<3		<0.08	<5
Pesticides													
PCB (total)	--		<0.002	<0.09		<0.002	<0.03		<0.002	<0.09		<0.002	<0.13

Note: Soil was maintained at typical field moisture content during plant growth. Values are on a dry weight basis in g/pot for yield, µg/g for content, and µg/pot for uptake.

* Table C5.

Table 18

Hypothetical Example of Toxicity of Four Puget Sound Sediments to Earthworms, *Eisenia foetida*

Treatment	Reference	Sediment A	 B	 C
Control	1	0	1	0
Exposed	0	98	1	0

Note: Soil was maintained at typical field moisture content during the test. Each treatment consisted of five replicates of 20 animals each. Values are mean percent mortality after 30 days.

Table 19

Hypothetical Example of Animal Growth, Tissue Content, and Total Uptake of Contaminants for the Earthworm *Eisenia foetida* Exposed to Four Puget Sound Sediments for 30 Days

Contaminants of Concern	Reference			Sediment								
				A			B			C		
	Yield	Content	Uptake	Yield	Content	Uptake	Yield	Content	Uptake	Yield	Content	Uptake
Growth	15.0			1.8			13.5			16.5		
As		3.36	50.4					8.91	1,203		1.87	30.8
Cd		4.05	60.7					7.02	94.8		8.17	134.1
Cu		160	2,400					250	3,375		170	2,805
Pb		2.9	43.5					200	2,700		105	1,732
Hg		0.012	1.8					0.008	0.108		0.20	3.3
Zn		125	1,875					190	2,565		165	2,722
Base/neutrals												
Naphthalene		0.005	0.075					0.85	11.5		0.25	4.1
Fluorene		0.001	0.015					0.54	7.3		0.50	8.2
Phenanthrene		0.015	0.225					0.75	10.1		0.55	9.1
Fluoranthene		0.002	0.03					2.55	34.4		0.45	7.4
Pyrene		0.055	0.82					1.05	14.2		0.09	1.5
Benzo(a)pyrene		0.050	0.75					5.25	70.9		0.050	0.8
Hexachlorobutadiene		0.008	0.12					0.31	4.2		0.160	2.6
Hexachlorobenzene		0.05	0.75					0.65	8.8		0.21	3.5
Acid extractable												
Pentachlorophenol		0.06	0.90					0.09	1.22		0.08	1.3
Pesticides												
PCB (total)		0.05	0.750					0.32	4.3		0.35	5.8

Note: Soil was maintained at typical field moisture content during the test. Values are on a dry weight basis in g/pot for yield, μg/g on a whole body basis for content, and μg/pot for uptake.

Table 20

Hypothetical Example of Concentrations of Dissolved Contaminants in the Saturated Zone

Leachate of a Nearshore Disposal Area Containing Three Puget Sound Sediments

Contaminants of Concern	Chronic Criterion-Saltwater*	Drinking Water Standard**	Reference Water	Sediment		
				A	B	C
As	--†	50	2	560	12	1
Cd	4.5	10	1	0.5	0.01	0.004
Cu	4.0	1,000	17	200	8.2	3.0
Pb	--	50	1.0	0.5	0.02	0.014
Hg	0.025	2	0.1	0.07	0.007	0.003
Zn	58	5,000	10	150	62.5	25
Base/neutrals						
Naphthalene	--	--	<1	<1	120	<1
Fluorene	--	--	<1	<1	10	<1
Phenanthrene	--	--	<1	<1	110	<1
Fluoranthene	--	--	<1	<1	150	12
Pyrene	--	--	<1	<1	11	<1
Benzo(a)pyrene	--	--	<1	<1	11	<1
Hexachlorobutadiene	--	--	<1	<1	10	<1
Hexachlorobenzene	--	--	<1	<1	10	<1
Acid extractable						
Pentachlorophenol	--	--	<1	<1	<1	<1
Pesticides						
PCB (total)	0.03	--	0.05	0.05	0.50	0.25

Note: Values are in µg/ℓ.

* Table C2.

** Table C4.

† --denotes value not established.

Table 21

Hypothetical Example of Toxicity of Effluents (Modified Elutriates) of Three Puget Sound Sediments

Species	Treatment % Modified Elutriate	Reference Site Water	Sediment		
			A	B	C
Surf perch (*Cymatogaster aggregata* juveniles)	0	0	0	0	0
	10	0	0	3	0
	50	1	13	6	1
	100	0	20	10	0
Mysid shrimp (*Neomysis americanus*)	0	0	0	0	0
	10	1	20	9	0
	50	1	65*	17	3
	100	3	83	22	0
Dungeness crab (*Cancer magister* larvae)	0	5	3	0	0
	10	0	7	4	3
	50	4	59**	28	7
	100	2	88	42	6
Oyster (*Crassostrea gigas* larvae)	0	2.1	1.6	2.9	1.8
	10	2.8	8.3	6.5	2.1
	50	4.4	58.4†	39.9	6.3
	100	6.4	91.2	68.2††	4.6

Note: Oyster data are mean percent abnormal larvae from two replicates per treatment after 48 hr. For other species each treatment consisted of three replicates of 10 animals each. Values are mean percent mortality after 96 hr, or mean percent abnormality after 48 hr for oysters.

* 96-hr LC50 is 39 percent modified elutriate.

** 96-hr LC50 is 44 percent modified elutriate.

† 48-hr EC50 for abnormality is 45 percent modified elutriate.

†† 48-hr EC50 for abnormality is 55 percent modified elutriate.

Table 22

Summary of Tentative Commencement Bay Area Authority Decisions Made for Three Sediments and Three Potential Disposal Environments Potential Using Hypothetical Test Results

Sediment	Potential Disposal Environment	Component	Tentative Decisions
A	Aquatic	Water column	Restrictions
		Benthic	Restrictions
	Upland	Effluent	Restrictions
		Runoff	Restrictions
		Leachate	Restrictions
		Plant uptake	Restrictions
		Animal uptake	Restrictions
		Human exposure	Restrictions
	Nearshore	Effluent	Restrictions
		Runoff	Restrictions
		Leachate	Restrictions
		Plant uptake	Restrictions
		Animal uptake	Restrictions
		Human exposure	Restrictions
B	Aquatic	Water column	Restrictions
		Benthic	Restrictions
	Upland	Effluent	No restrictions
		Runoff	No restrictions
		Leachate	Restrictions
		Plant uptake	Restrictions
		Animal uptake	Restrictions
		Human exposure	No restrictions
	Nearshore	Effluent	No restrictions
		Runoff	No restrictions
		Leachate	Restrictions
		Plant uptake	Restrictions
		Animal uptake	Restrictions
		Human exposure	No restrictions
C	Aquatic	Water column	No restrictions
		Benthic	Restrictions
	Upland	Effluent	No restrictions
		Runoff	No restrictions
		Leachate	No restrictions
		Plant uptake	No restrictions
		Animal uptake	Restrictions
		Human exposure	No restrictions
	Nearshore	Effluent	Restrictions
		Runoff	No restrictions
		Leachate	Restrictions
		Plant uptake	No restrictions
		Animal uptake	Restrictions
		Human exposure	No restrictions

APPENDIX A: DECISIONMAKING FRAMEWORK FOR AQUATIC DISPOSAL

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* NOTE: Alphanumeric identification of pages, paragraphs, and figures was used in the appendices to distinguish them from the simple numbers used as identification of main-text pages, paragraphs, figures, and tables. Thus references to simple numbers in the appendices refer to similarly numbered items in the main text.

APPENDIX A: DECISIONMAKING FRAMEWORK FOR AQUATIC DISPOSAL

A1. Concerns about contaminant impacts from aquatic disposal have centered on short-term impacts in the water column during and immediately after disposal and on long-term impacts of the deposited sediment on the benthic environment after disposal. The tests appropriate for determining the possibility of these impacts occurring are different and are shown separately in Figure A1.

Water Column Evaluation

A2. The possibility of water column impacts of contaminants released by dredged material disposal has been recognized and intensively studied for years. These studies have included dredged material containing high concentrations of a wide variety of metals and organic contaminants discharged from hoppers, barges, and pipelines, and have included both laboratory and field investigations. *The overwhelming preponderance of evidence from these studies demonstrates no unacceptable adverse impacts on the water column from contaminants in dredged material* (Arimato and Feng 1983; Brannon 1978; Burks and Engler 1978; DeLoach and Waring 1984; Hirsch, et al. 1978; Stewart 1984; Sullivan and Hancock 1977; Sweeney 1977; Tatem and Johnson 1977; Tramontano and Bohlen, 1984; Wright 1977 and 1984*). The most likely situations in which aquatic disposal may produce contaminant-associated impacts in the water column involve prolonged high volume discharges into small, poorly mixed water bodies or embayments. These make very poor disposal sites for reasons unrelated to contaminants and are very seldom proposed for such use.

A3. Studies such as those cited above do not prove that water column impacts will not occur with aquatic disposal. However, they do indicate that such impacts are sufficiently unlikely that the local authority must decide whether it is appropriate to divert funds for testing for potential water column impacts in association with disposal in aquatic sites where rapid dispersion and dilution will occur. In many cases it will be possible to assess the potential for water column impacts on the basis of previous water column testing and characteristics of the disposal site without conducting additional sediment-specific testing.

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* References are listed at the end of the main text.

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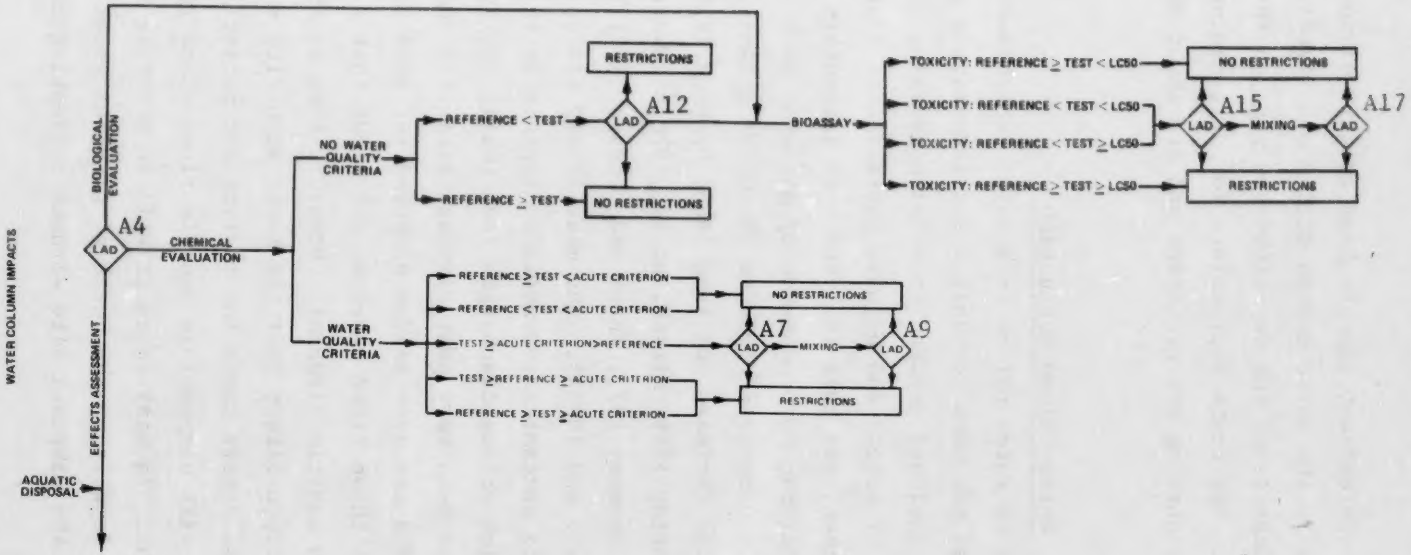
WATER COLUMN IMPACTS
AQUATIC DISPOSAL
EFFECTS ASSESSMENT
BIOLOGICAL EVALUATION
LAD
A4
CHEMICAL EVALUATION
NO WATER QUALITY CRITERIA
REFERENCE < TEST
REFERENCE ≥ TEST
LAD
A12
RESTRICTIONS
NO RESTRICTIONS
BIOASSAY
TOXICITY: REFERENCE ≥ TEST < LC50
TOXICITY: REFERENCE < TEST < LC50
TOXICITY: REFERENCE < TEST ≥ LC50
TOXICITY: REFERENCE ≥ TEST ≥ LC50
NO RESTRICTIONS
LAD
A15
MIXING
LAD
A17
RESTRICTIONS
WATER QUALITY CRITERIA
REFERENCE ≥ TEST < ACUTE CRITERION
REFERENCE < TEST < ACUTE CRITERION
TEST ≥ ACUTE CRITERION > REFERENCE
TEST ≥ REFERENCE ≥ ACUTE CRITERION
REFERENCE ≥ TEST ≥ ACUTE CRITERION
NO RESTRICTIONS
LAD
A7
MIXING
LAD
A9
RESTRICTIONS

Figure A1. Flowchart for decisionmaking for aquatic disposal benthic impacts (number near LAD is paragraph discussing LAD)

A4. If the local authority chooses to conduct additional tests to assess the potential for contaminant impacts in the water column, the procedures outlined in Figure A1 should be followed. Water column evaluations are based on the standard elutriate (paragraph 28). However, the local authority must decide whether to take a chemical- or biological-based approach to evaluating potential impacts on the water column. Chemical evaluations are appropriate when concern is primarily with chemicals for which water-quality criteria have been established (Table C2) and there is little concern about interactive effects of multiple contaminants. If the concern is primarily with chemicals for which water-quality criteria have not been established, or there is concern about interactive effects of multiple contaminants, a biological approach is preferred.

DECISIONS FROM CHEMICAL EVALUATIONS

A5. Chemical analyses of the elutriate are evaluated in comparison to dissolved contaminant concentrations in reference water and to acute water-quality criteria for contaminants for which criteria exist (Table C2). Acute criteria are maximum concentrations that should not be exceeded and are appropriate because of the transient nature of dredged material contaminant releases to the water column. Contaminants for which criteria exist are evaluated separately from those for which criteria have not been established.

A6. When acute water-quality criteria exist for the contaminants of concern, five conditions are possible (Figure A1):

a. Concentrations of all dissolved contaminants in the test water (elutriate) are *less than or equal to* the reference water and *less than or equal to* the acute water-quality criterion for each contaminant (Table C2).

b. Concentration of any dissolved contaminant in the test is *greater than* in the reference water and *less than or equal to* the acute water-quality criterion (Table C2).

Conditions a and b lead to a DECISION OF NO RESTRICTIONS required to protect against degradation of the water column beyond existing reference site conditions.

c. Concentration of any dissolved contaminant in the test is *less than or equal to* the reference water and *greater than* the acute water-quality criterion (Table C2).

d. Concentration of any dissolved contaminant in the test is *equal to or greater than* the reference water, and the reference water is *equal to or greater than* the acute water quality criterion (Table C2).

Since dilution to the criterion cannot occur under conditions c and d (unless the receiving water for the discharge is not the reference water and is less than the criterion), they lead to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the water column due to the proposed discharge. Some potentially appropriate restrictions are described in paragraphs 75 and 76.

e. Concentration of any dissolved contaminant in the test is *equal to or greater than* the acute water-quality criterion (Table C2), and the reference water is *less than* the acute water-quality criterion.

Since dilution to the criterion can occur (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion), this leads to a LOCAL AUTHORITY DECISION as discussed in paragraph A7.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER MIXING

A7. Under the conditions of subparagraph A6e, dilution will occur at the disposal site (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion). Therefore, mixing must be considered in order to scientifically assess the potential for water column impacts to occur. However, in some cases, the local authority may choose to reach a decision without considering mixing by assessing test results in light of the increasing concern about potential contaminant impacts in the water column in direct relation to the:

a. Number of contaminants (for which criteria have been established) exceeding reference concentrations.

b. Number of contaminants (with criteria) exceeding acute criteria.

c. Magnitude by which reference concentrations are exceeded.

d. Magnitude by which criteria are exceeded.

e. Toxicological importance of contaminants exceeding reference concentrations and/or acute criteria. Contaminants that can be objectively ranked in this manner are presented in Table C3.

f. Proportion of sediment sampling sites in the dredging area being evaluated that have elutriate exceeding reference concentrations and/or acute criteria. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

In the case of subparagraph A6e, the local authority might choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. *This may be appropriate if* *samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount and are well below the acute criteria.* In addition to the preceeding contaminant considerations, the discharge should also be subjectively assessed in light of the mixing considerations of paragraph 34 before a decision of no restrictions is reached. In the case of subparagraph A6e, the local authority might also choose, without considering mixing, to reach a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the water column. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference and the criteria by a substantial margin.* A decision for restrictions would be particularly appropriate in cases where the water at the disposal site already exceeded the criterion, making dilution to the criterion impossible. Some potentially appropriate restrictions are described in paragraphs 75 and 76. If the local authority desires to fully evaluate the potential for water column impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph A9.

A8. *Commencement Bay area authorities have tentatively decided to make the local authority decision (LAD) discussed in paragraph A7 using the following quantitative approach. The quantitation was selected for use when Commencement Bay area goals (paragraph 70) indicate the use of a relatively pristine reference, as is the case in the example of Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph A7 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

> a. If *25 percent or less* of the contaminants of concern (for which criteria have been established) exceed reference, there is cause for *low concern*. If *25 percent-90 percent* of the contaminants of concern with criteria exceed reference, there is

cause for *moderate concern*. If *90 percent or more* of the contaminants of concern with criteria exceed reference, there is cause for *high concern*.

b. If *25 percent or less* of the contaminants of concern with criteria exceed the criteria, there is cause for *low concern*. If *25 percent-75 percent* of the contaminants of concern with criteria exceed the criteria, there is cause for *moderate concern*. If *75 percent or more* of the contaminants of concern with criteria exceed the criteria, there is cause for *high concern*.

c. If the contaminant of concern (with a criterion) that exceeds reference by the greatest factor is *less than or equal to 25 times* reference concentration, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *25-100 times* reference concentration, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *100 or more times* reference concentration, there is cause for *high concern*.

d. If the contaminant of concern (with a criterion) that exceeds its criterion by the greatest factor is *less than or equal to 10 times* its criterion, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *10-100 times* its criterion, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *100 or more times* its criterion, there is cause for *high concern*.

e. If all contaminants of concern (with criteria) are *rank 1 or 2* in Table C3, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *rank 3 or 4* in Table C3, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *rank 5 or 6* in Table C3, there is cause for *high concern*. (Unranked contaminants of concern are cause for *moderate concern* unless there is additional evidence to reasonably warrant a different level of concern.)

f. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated have any contaminant of concern (with a criterion) exceeding the reference or criterion, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites in the area being evaluated have any contaminant of concern (with a criterion) exceeding the reference or criterion, there is cause for *high concern*. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

Findings of *low concern in all factors*, a through f, lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. A finding of *high concern* in half or more factors leads to a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 75 and 76. All other combinations of findings lead to a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph A10.

DECISION FOR FURTHER EVALUATION: CONSIDER MIXING

A9. If the considerations of paragraph A7 lead to an evaluation of mixing, the local authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to the water quality criteria are acceptable. Mixing zone calculation is described in paragraphs 31-33 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing zone evaluation is discussed in paragraphs 34-36 and can result in:

a. A mixing zone of *acceptable* size and configuration within which the discharge will be diluted to *less than* the acute water-quality criterion (Table C2). Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph A7 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column.

b. The mixing zone within which the discharge will be diluted to less than the acute water-quality criterion (Table C2) is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph A7 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 75 and 76.

A10. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph A9 using the following quantitative approach. The quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example of Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph A7 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. A DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *acceptable* (paragraph 35) *and* there is cause for low concern if *any four of the six* factors in paragraph A8 considered at the edge of the mixing zone.

b. A DECISION OF RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *unacceptable* (paragraph 35) or there is cause for *moderate or high* concern in *any four of the six* factors in paragraph A8 considered at the edge of the mixing zone. Some potentially appropriate restrictions are described in paragraphs 75 and 76.

A11. When acute water-quality criteria do not exist for contaminant(s) of concern, two conditions are possible (Figure A1).

a. Concentrations of *all* dissolved contaminants of concern in the test water (elutriate) are *less than or equal to* the reference water. This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the water column beyond existing reference site conditions.

b. Concentration of *any* dissolved contaminant in the test water is *greater* than in the reference water. This leads to a LOCAL AUTHORITY DECISION.

A12. LOCAL AUTHORITY DECISION: BIOASSAYS. Under the conditions of subparagraph A11b, the local authority must decide whether to require bioassays. There is no basis for determining the environmental importance of a contaminant that exceeds the reference concentration unless bioassays are conducted. However, in some cases the local authority could choose to reach a decision without conducting bioassays by assessing test results in light of the increasing concern about potential contaminant impacts in the water column in direct relation to the factors listed in paragraph A7. In the case of subparagraph A11b, the local authority might choose, without conducting bioassays, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. *This may be appropriate if samples from only a few sites have a small number of contaminants exceeding the reference by a small amount.* Since there are no criteria, if bioassays are not considered necessary on the above basis, there is no "target concentration" for a mixing calculation. However, in addition to the contaminant considerations of paragraph A7, the discharge should also be subjectively assessed in light of the mixing considerations of paragraph 34 before a DECISION OF NO RESTRICTIONS is reached. On the other hand, the local authority might choose, without conducting bioassays, to reach a DECISION FOR RESTRICTIONS *if samples from a* *number of sites have several contaminants exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 75 and 76. If the local authority desires to fully evaluate the potential for water column impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by conducting bioassays as evaluated in paragraph A14. This will determine the effects of exceeding the reference for short periods and will indicate possible interactive effects of multiple contaminants.

A13. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph A12 using the quantitative approach described in paragraph A8. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example of Part III and Tables 3-21. Other values may be necessary to achieve goals that utilize a less pristine reference. Since there are no water-quality criteria for the contaminants presently under consideration, factors b and d are simply excluded from consideration, and the other factors evaluated as described in paragraph A8. If a* DECISION FOR FURTHER EVALUATION *is reached, bioassays must be conducted and evaluated as described in paragraph A14. Although conceptually similar approaches to interpreting elutriate test results in the absence of water-quality criteria could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph A12 or its quantitation in the above manner since the guidance considerations may be complexly interactive. The approach described above is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

DECISIONS FROM BIOLOGICAL EVALUATIONS

A14. From this point on, the evaluation of potential water column impacts is biological. It is at this point that testing begins if a biological approach is initially chosen in paragraph A4 (Figure A1). Water column bioassays can result in four possible conditions:

a. Toxicity of the test water (elutriate) to all species is *less than or equal to* the reference water and *less than* the LC50 (i.e., 50-percent toxicity is not reached in the test water). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column.

b. Toxicity of the test water to any species is *less than or equal to* the reference water and *equal to or greater than* the LC50 (i.e., at least 50-percent toxicity is reached in the test water). This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 75 and 76.

c. Toxicity of the test water to any species is *greater than* the reference water and *less than* the LC50, or

d. Toxicity of the test water to any species is *greater than* the reference water and *equal to or greater than* the LC50. (Therefore, dilution to the LC50 is possible if the receiving water for the discharge, which may or may not be the reference water, is less than the LC50.)

Conditions c and d lead to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER MIXING.

A15. Under the condition of subparagraphs A14c or d, dilution will occur at the disposal site (if the receiving water for the discharge, which may or may not be the reference water, is less than the LC50). Therefore, mixing must be considered in order to scientifically assess the potential for water column impacts to occur. However, in some cases the local authority could choose to reach a decision without considering mixing by assessing test results in light of the increasing concern about potential contaminant impacts in the water column in direct relation to the:

a. Number of species bioassayed with the elutriate with toxicity exceeding reference toxicity.

b. Magnitude of test toxicity.

c. Magnitude by which reference toxicity is exceeded.

d. Proportion of sediment sampling sites in the dredging area being evaluated that have elutriates whose toxicity exceeds reference toxicity. (If a single composite sample from the dredging area is bioassayed, this factor drops from consideration.)

In the case of subparagraph A14c, the local authority might choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. *This may be appropriate if samples from only a few sites are toxic to a low number of species and the toxicity only slightly exceeds reference toxicity and is well below the LC50.* In the case of subparagraph A14d, the local authority might choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the water column. *This may be appropriate if samples from a number of sites are toxic to several species and the toxicity* *exceeds the reference toxicity and 50 percent by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 75-80. If the local authority desires to fully evaluate the potential for water column impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph A17.

A16. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph A15 using the following quantitative approach. The quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example of Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph A15 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. If the elutriate produces greater toxicity than the reference material in *20 percent or less* of the test species, there is cause for *low concern*. If elutriate toxicity exceeds reference toxicity in *20 percent-80 percent* of the test species, there is cause for *moderate concern*. If elutriate toxicity exceeds reference toxicity in *80 percent or more* of the test species, there is cause for *high concern*.

b. If the elutriate produces toxicity *20 percentage points* or less* above the control in all test species, there is cause for *low concern**. If elutriate toxicity is *20-40 percentage points** above control toxicity in any species, there is cause for *moderate concern*. If elutriate toxicity is *40 percentage points* or more* above control toxicity in any species, there is cause for *high concern*.

c. If the elutriate produces toxicity in all species *less than or equal to 2 times* the reference material toxicity, there is cause for *low concern*. If elutriate toxicity is *2-40 times* reference toxicity in any species, there is cause for *moderate concern*. If elutriate toxicity is *40 or more times* the reference toxicity in any species, there is cause for *high concern*.

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* For example, if 2 of 100 control animals (2 percent) show toxicity, then at least 12 of 100 test animals (12 percent) would have to show toxicity in order for toxicity of the test sediment to be 10 percentage points above the control.

d. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated have elutriate toxicity to any species exceeding the reference toxicity, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites in the area being evaluated have elutriate toxicity to any species exceeding the reference toxicity, there is cause for *high concern*. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

Findings of *low concern in all factors* a through d lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. A finding of *high concern* in any three of the four factors leads to a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 75-80. All other combinations of findings lead to a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph A18.

DECISION FOR FURTHER EVALUATION: CONSIDER MIXING

A17. If the considerations of paragraph A15 lead to an evaluation of mixing, the local authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to less than the LC50 concentration are acceptable. Mixing zone calculation is described in paragraphs 31-33 and Appendix D. *Note that mixing calculations must be based on the receiving water from the discharge, which may or may not be the reference water.* Mixing zone evaluation is discussed in paragraphs 34-36 and can result in:

a. A mixing zone of *acceptable* size and configuration within which the discharge will be diluted to less than the LC50. Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph A15 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column. (In the case of subparagraph A14c, the LC50 is not exceeded even without consideration of mixing, but if desired the mixing zone to dilute to some lower value, such as LC20, can be calculated.)

b. A mixing zone (within which the discharge will be diluted to less than the LC50) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph A15 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 75-76.

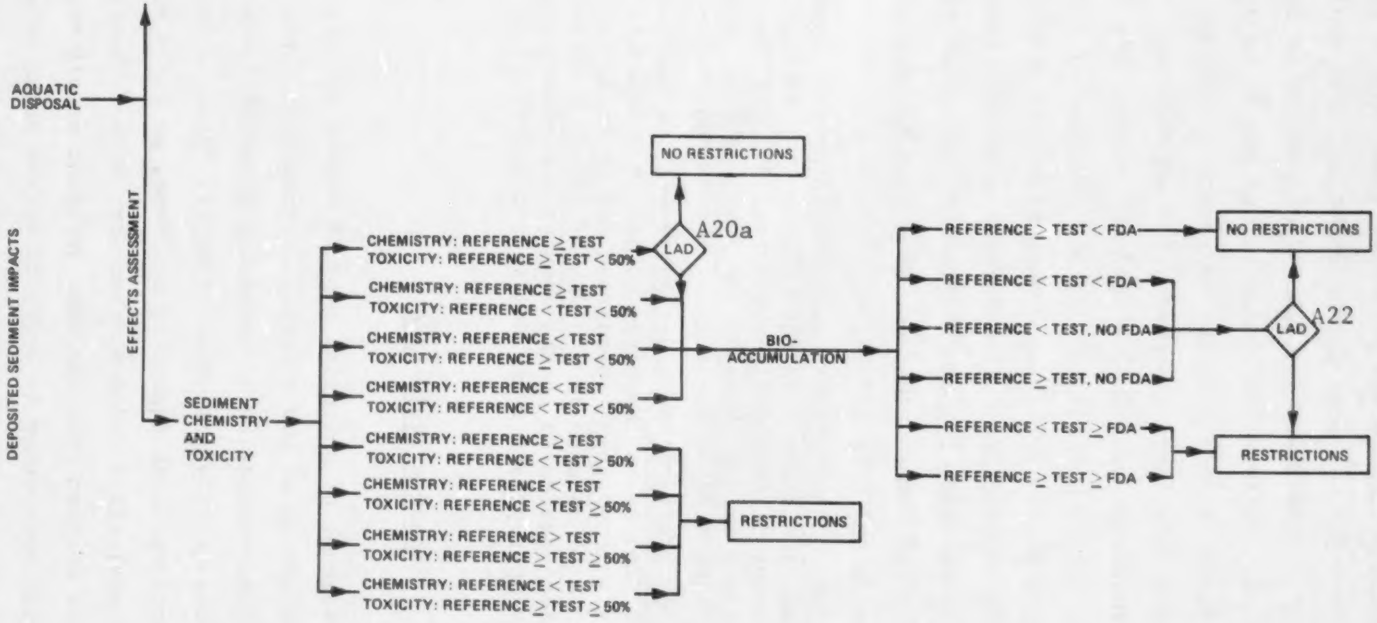
A18. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph A15 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example of Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph A15 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. A DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *acceptable* (paragraph 35) *and* there is cause for low concern in *any three of the four* factors in paragraph A16 considered at the edge of the mixing zone.

b. A DECISION OF RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *unacceptable* (paragraph 35) *or* there is cause for *moderate or high* concern in *any two of the four* factors in paragraph A16 considered at the edge of the mixing zone. Some potentially appropriate restrictions are described in paragraphs 75-76.

Benthic Evaluation

A19. A thorough assessment of potential impacts should include both chemical and biological evaluation of the material in question. This is accomplished in the water column evaluation by comparing chemical concentrations to biologically derived water-quality criteria. However, in the case of nondissolved contaminants associated with deposited sediment, no biological-based criteria are available for evaluating sediment chemistry data. Therefore, chemical and biological data derived from the same sediment sample must be evaluated in conjunction with each other in order to arrive at an adequate assessment of potential impacts on the benthic environment (Figure A2). This is accomplished by using a bulk or total sediment analysis for the specific


DEPOSITED SEDIMENT IMPACTS
AQUATIC DISPOSAL
EFFECTS ASSESSMENT
SEDIMENT CHEMISTRY AND TOXICITY
CHEMISTRY: REFERENCE ≥ TEST
TOXICITY: REFERENCE ≥ TEST < 50%
CHEMISTRY: REFERENCE ≥ TEST
TOXICITY: REFERENCE < TEST < 50%
CHEMISTRY: REFERENCE < TEST
TOXICITY: REFERENCE ≥ TEST < 50%
CHEMISTRY: REFERENCE < TEST
TOXICITY: REFERENCE < TEST < 50%
CHEMISTRY: REFERENCE ≥ TEST
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CHEMISTRY: REFERENCE < TEST
TOXICITY: REFERENCE < TEST ≥ 50%
CHEMISTRY: REFERENCE > TEST
TOXICITY: REFERENCE ≥ TEST ≥ 50%
CHEMISTRY: REFERENCE < TEST
TOXICITY: REFERENCE ≥ TEST ≥ 50%
LAD
A20a
NO RESTRICTIONS
RESTRICTIONS
BIO-ACCUMULATION
REFERENCE ≥ TEST < FDA
REFERENCE < TEST < FDA
REFERENCE < TEST, NO FDA
REFERENCE ≥ TEST, NO FDA
REFERENCE < TEST ≥ FDA
REFERENCE ≥ TEST ≥ FDA
NO RESTRICTIONS
LAD
A22
RESTRICTIONS

Figure A2. Flowchart for decisionmaking for aquatic disposal benthic impacts (number near LAD is paragraph discussing LAD)

contaminants of concern identified for that particular sediment and a toxicity test of the whole sediment (paragraph 39).

DECISIONS FROM CHEMISTRY AND TOXICITY EVALUATIONS

A20. Chemical analyses of the test sediment are compared to similar analyses of a sedimentologically similar reference sediment. Toxicity of the test sediment is statistically compared to toxicity of the same reference sediment to the same appropriately sensitive aquatic organisms. Benthic chemistry and toxicity tests can result in eight possible combinations:

a. Concentration of *all* contaminants of concern in the test sediment are *less than or equal to* the reference sediment, and toxicity of the test sediment to all species is *less than or equal to* the reference and *less than* 50 percentage points above the control.* This leads to a LOCAL AUTHORITY DECISION. The LAD might be NO RESTRICTIONS. This may be appropriate if concentrations of all contaminants of concern in the test sediment were considerably *less than* reference and toxicity of the test sediment to all species was considerably *less than* the reference. The LAD might be a DECISION FOR FURTHER EVALUATION by assessing the potential for bioaccumulation as discussed in paragraph A21. This might be appropriate if concentrations of all contaminants of concern and toxicity to all species equals reference.

b. Concentrations of *any* contaminant of concern in the test sediment are *less than or equal to* the reference sediment, and toxicity of the test sediment to any species is *greater than* the reference and *less than* 50 percentage points above the control,* or

c. Concentrations of *any* contaminant of concern in the test sediment are *greater than* the reference sediment, and toxicity of the test sediment to any species is *less than or equal to* the reference sediment and *less than* 50 percentage points above the control,* or

d. Concentrations of *any* contaminant of concern in the test sediment are *greater than* the reference sediment, and toxicity of the test sediment to any species is *greater than* the reference sediment and *less than* 50 percentage points above the control.*

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* For example, if 9 of 100 control animals (9 percent) show toxicity, then at least 59 of 100 test animals (59 percent) would have to show toxicity in order for toxicity of the test sediment to be 50 percentage points above the control.

Conditions b, c, and d lead to a DECISION FOR FURTHER EVALUATION by assessing the potential for bioaccumulation of the contaminants of concern from the test sediment (Figure A2), as discussed in paragraph A21.

e. Concentrations of *any* contaminant of concern in the test sediment are *less than or equal to* the reference sediment, and toxicity of the test sediment to any species is *greater than* the reference and *equal to or greater* than 50 percentage points above the control,* or

f. Concentrations of *any* contaminant of concern in the test sediment are *greater than* the reference sediment, and toxicity of the test sediment to any species is *greater than* the reference and *equal to or greater* than 50 percentage points above the control, or

g. Concentrations of *any* contaminant of concern in the test sediment are *less than or equal to* the reference sediment, and toxicity of the test sediment to any species is *less than or equal to* the reference sediment and *equal to or greater than* 50 percentage points above the control,* or

h. Concentrations of *any* contaminant of concern in the test sediment are *greater than* the reference sediment, and toxicity of the test sediment to any species is *less than or equal to* the reference sediment and *equal to or greater than* 50 percentage points above the control.*

Conditions e, f, g, and h lead to a DECISION FOR RESTRICTIONS required to protect against possible contaminant degradation of the benthic environment beyond existing reference site conditions. Some potentially appropriate restrictions are described in paragraphs 77-79.

DECISIONS FROM BIOACCUMULATION EVALUATIONS

A21. The local authority must evaluate the potential for bioaccumulation of contaminants from sediments as indicated by the procedures of paragraph 40. Bioaccumulation tests can result in six conditions:

a. Concentrations of *all* contaminants of concern in the tissues of *any* species exposed to the test sediment are *less than or equal to* concentrations in animals exposed to the reference sediment and *less than* FDA-type limits (Table C1). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts due to sediment deposits.

b. Concentration of *any* contaminant of concern in the tissues of *any* test species are *greater than* reference animals and *equal to or greater than* FDA-type limits (Table C1), or

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* For example, if 9 of 100 control animals (9 percent) show toxicity, then at least 59 of 100 test animals (59 percent) would have to show toxicity in order for toxicity of the test sediment to be 50 percentage points above the control.

c. Concentrations of *any* contaminant of concern in the tissues of *any* test species are *less than or equal to* reference animals and *equal to or greater than* FDA-type limits (Table C1).

Conditions b and c lead to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts of sediment deposits. Some potentially appropriate restrictions are described in paragraphs 77-79.

d. Concentrations of *any* contaminant of concern in the tissues of *any* test species are *greater than* reference animals and *less than* FDA-type limits (Table C1), or

e. Concentrations of *any* contaminant of concern in the tissue of *any* test species are greater than reference animals and *no FDA-type limits have been established* (Table C1), or

f. Concentrations of *any* contaminant of concern in the tissues of *any* test species are *less than or equal to* reference animals and *no FDA-type limits have been established* (Table C1).

Conditions d, e, and f lead to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: NEED FOR RESTRICTIONS

A22. At present it is not possible to provide sufficient scientific basis for deciding on the need for restrictions on the cases of subparagraphs A21d, e, and f. Therefore, the local authority must make an administrative decision using the available scientific information and locally important concerns. In interpreting bioaccumulation data, scientific concern over potential adverse impacts associated with bioaccumulation increases in direct relation to:

a. Number of contaminants of concern bioaccumulated to concentrations exceeding reference levels.

b. Number of phylogenetic groups of species showing bioaccumulation to concentrations exceeding reference levels.

c. Magnitude of contaminant concentrations in tissues of test organisms.

d. Magnitude of bioaccumulation above reference levels.

e. Toxicological importance of contaminants bioaccumulated to concentrations exceeding reference levels. Contaminants which can be objectively ranked in this manner are presented in Table C3.

f. Number of species showing toxicity when exposed to the same test sediment.

g. Magnitude of toxicity caused by the same test sediment.

h. Proportion of sediment sampling sites in the area being evaluated which show toxicity exceeding reference or bioaccumulation to concentrations exceeding reference levels.

When bioaccumulation test results are those of subparagraphs A21d, e, and f, these considerations may lead the local authority to a DECISION FOR RESTRICTIONS to protect from possible adverse contaminant impacts from sediment deposits on the aquatic environment. Some potentially appropriate restrictions for such cases are discussed in paragraphs 75 and 77-79. The local authority may also reach a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts from sediment deposits.

A23. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph A22 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (Paragraph 70) require the use of a relatively pristine reference, as is the case in the example of Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph A22 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. Number of contaminants above reference. If *25 percent or less* of the contaminants of concern are bioaccumulated in any species to concentrations exceeding those in reference animals, there is cause for *low concern*. If *more than 25 percent* of the contaminants of concern in any species exceed reference animals, there is cause for *high concern*.

b. Number of species. If the dredged material produces higher tissue concentrations of any contaminant than the reference material in *20 percent or less* of the test species, there is cause for *low concern*. If the dredged material produces higher concentrations of any contaminant than the reference material in *more than 20 percent* of the test species, there is cause for *high concern*.

c. Tissue contaminant concentrations. If the dredged material produces tissue contaminant concentrations of *0.5 μg/g wet weight or less* of all contaminants in all species, there is cause for *low concern*. If the dredged material produces tissue contaminant concentrations *greater than 0.5 μg/g wet weight* of any contaminant in any species, there is cause for *high concern*.

d. Magnitude above reference. If the dredged material produces tissue concentrations of all contaminants in all species *10 or less times* higher than the reference tissue concentrations, there is cause for *low concern*. If the dredged material tissue concentrations of any contaminant in any species are *more than 10 times* the reference concentrations, there is cause for *high concern*.

e. Toxicological importance. If the contaminants of concern bioaccumulated to concentrations exceeding reference levels in any species are *rank 1-3* in Table C3, there is cause for *low concern*. If the bioaccumulated contaminants in any species are *unranked or rank 4-6* in Table C3, there is cause for *high concern*.

f. Toxicity above reference. If the dredged material produces more toxicity than the reference material in *20 percent or less* of the deposited sediment bioassay species, there is cause for *low concern*. If deposited dredged material toxicity exceeds reference toxicity in *more than 20 percent* of the test species, there is cause for *high concern*.

g. Toxicity above control. If the deposited dredged material produces toxicity *20 percentage points* or less* above the control in all test species, there is cause for *low concern*. If deposited dredged material toxicity is *more than 20 percentage points** above control in any species, there is cause for *high concern*.

h. Number of sampling sites producing bioaccumulation. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated produce bioaccumulation of any contaminant in any species exceeding the reference sediment, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites produce bioaccumulation of any contaminant of concern in any species exceeding the reference sediment, there is cause for *high concern*.

i. Number of sampling sites producing toxicity. If *50 percent or less* of the sediment sampling sites in the area being evaluated produce toxicity to any species exceeding the reference sediment, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites produce toxicity to any species exceeding the reference sediment, there is cause for *high concern*. (If a single composite sample from the dredging area is analyzed, factor h and i drop from consideration.)

j. Number of contaminants in sediment above reference. If the bulk sediment concentration of *50 percent or less* of the contaminants of concern is higher in the dredged material than the reference material, there is cause for *low concern*. If the bulk sediment concentration of *more than 50 percent* of the contaminants of concern is higher in the dredged material than in the reference material, there is cause for *high concern*.

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* For example, if 6 of 100 control animals (6 percent) show toxicity, then at least 26 of 100 test animals (26 percent) would have to show toxicity in order for toxicity of the test sediment to be 20 percentage points above the control.

k. Magnitude above reference-sediment metals. If the metal contaminant of concern with the highest bulk sediment concentration in the dredged material is *5 or less times* higher than in the reference material, there is cause for *low concern*. If the metal contaminant of concern with the highest bulk sediment concentration in the dredged material is *more than 5 times* higher than in the reference material, there is cause for *high concern*.

l. Magnitude above reference-sediment organics. If the organic contaminant of concern with the highest TOC-normalized bulk sediment concentration in the dredged material is *10 or less times* higher than in the reference material, there is cause for *low concern*. If such concentrations in the dredged material are *more than 10 times* higher than in the reference, there is cause for *high concern*.

Findings of *low concern* in *more than half* the factors lead to a DECISION OF NO RESTRICTIONS required to protect from possible adverse impacts of sediment deposits on the aquatic environment. A finding of *high concern* in *more than half* the factors leads to a DECISION OF RESTRICTIONS required to protect from possible adverse contaminant impacts of sediment deposits on the aquatic environment. Some potentially appropriate restrictions for such cases are discussed in paragraphs 75 and 77-79.

APPENDIX B: DECISIONMAKING FRAMEWORK FOR UPLAND DISPOSAL

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* NOTE: Alphanumeric identification of pages, paragraphs, and figures was used in the appendices to distinguish them from the simple numbers used as identification of main-text pages, paragraphs, figures, and tables. Thus references to simple numbers in the appendices refer to similarly numbered items in the main text.

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APPENDIX B: DECISIONMAKING FRAMEWORK FOR UPLAND DISPOSAL

B1. There are six aspects of upland disposal that require consideration as shown in Figure B1. At this time, there are only two simplified laboratory tests that indicate a potential for contaminant mobility from sediment to be dredged into two of these aspects, effluent water quality and plant uptake. There are no other existing simplified laboratory tests to address contaminant mobility into surface runoff, leachate water quality, or animal uptake. Research is needed to develop those tests. There are more sophisticated laboratory tests that are recommended for surface runoff and plant and animal uptake but no specified leachate tests. Research is being initiated at the WES to address leachate testing. Potential human exposure can be evaluated by comparing the total concentration of contaminants in the dredged material to recently tabulated critical concentrations of contaminants of concern for human exposure.

B2. There are four flowcharts (Figures B2-B5) that show decision points for the three water-quality aspects of upland disposal. Two additional flowcharts (Figures B6 and B7) show decision points for plant and animal aspects of upland disposal. Figure B8 shows decision points for potential human exposure.

B3. The first tests that should be conducted on a contaminated dredged material are a total bulk chemical analysis if not already performed (paragraph 72), a modified elutriate test (paragraph 45), and a DTPA extraction procedure (paragraph 62). The results of these tests will give an indication of the need for restrictions on human exposure, restrictions on effluent quality control, and further testing of plant uptake. These test results are limited in relationship to estimating surface runoff quality, leachate quality, or animal uptake.

Effluent Quality Tests

B4. Concerns about contaminant impacts from upland disposal site effluent water have centered on short-term impacts in the receiving water during the disposal operation. The decision points and the tests appropriate for determining potential impacts from disposal site effluent water are shown in Figure B2. The local authority must decide whether to take a chemical or biological based approach to evaluating the potential impacts of the disposal site effluent on the receiving water. Chemical evaluations are appropriate

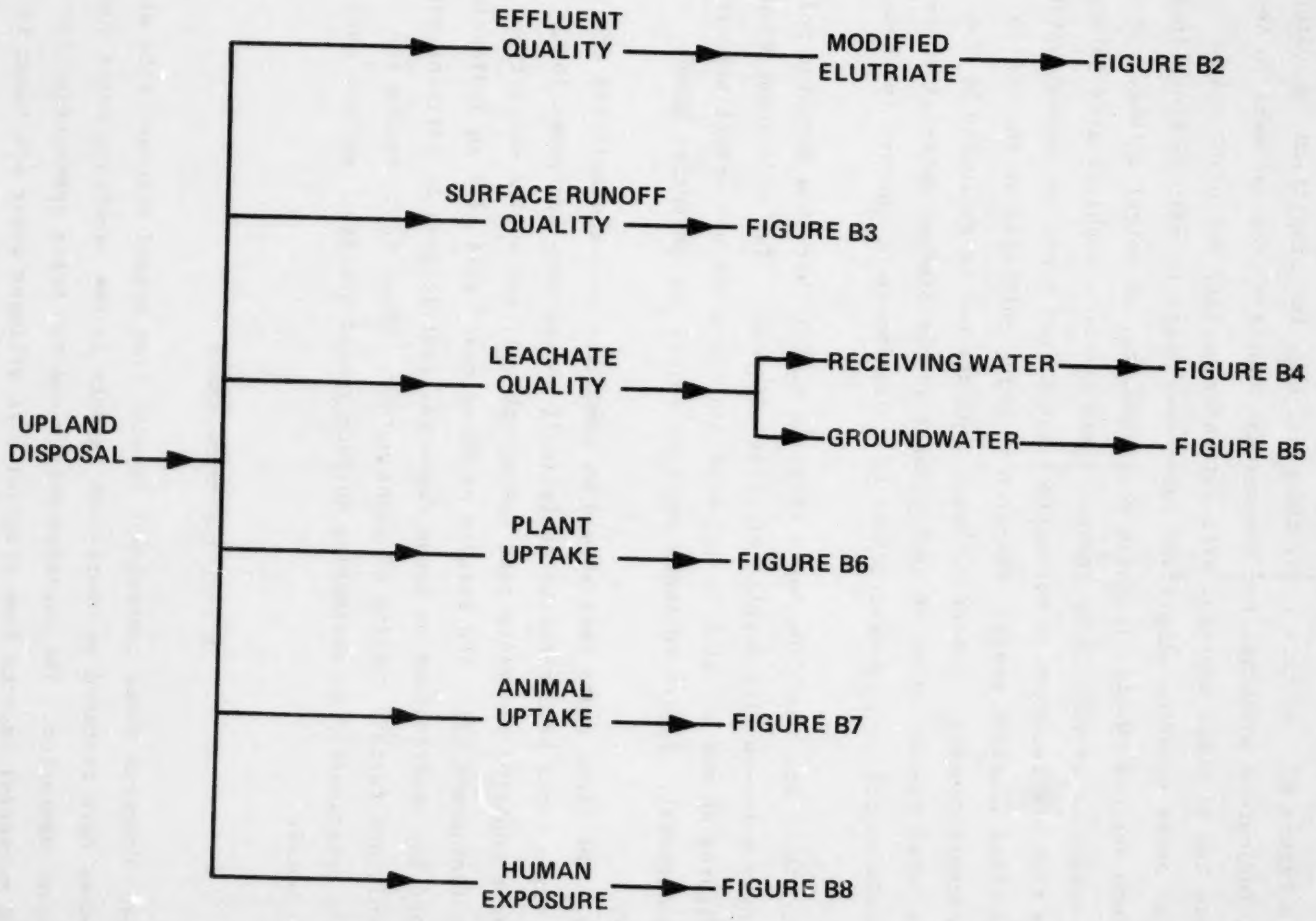
UPLAND DISPOSAL
EFFLUENT QUALITY
MODIFIED ELUTRIATE
FIGURE B2
SURFACE RUNOFF QUALITY
FIGURE B3
LEACHATE QUALITY
RECEIVING WATER
FIGURE B4
GROUNDWATER
FIGURE B5
PLANT UPTAKE
FIGURE B6
ANIMAL UPTAKE
FIGURE B7
HUMAN EXPOSURE
FIGURE B8

Figure B1. Summary flowchart for decisionmaking for upland disposal

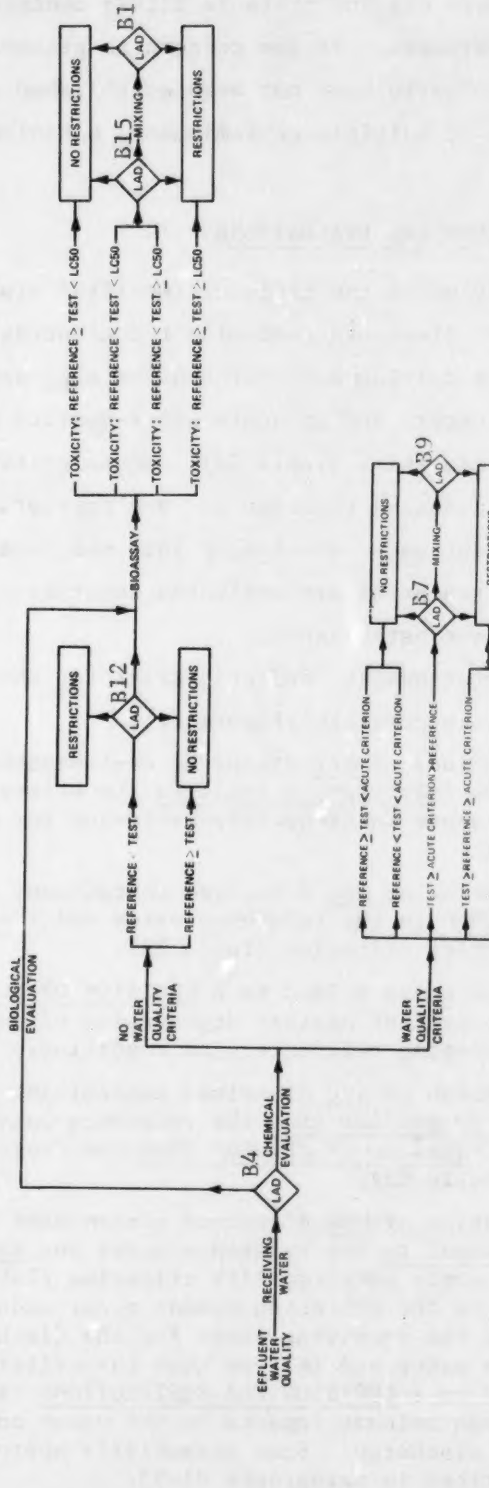
EFFLUENT WATER QUALITY
RECEIVING WATER
LAD
B4
CHEMICAL EVALUATION
BIOLOGICAL EVALUATION
NO WATER QUALITY CRITERIA
REFERENCE < TEST
REFERENCE ≥ TEST
LAD
B12
RESTRICTIONS
NO RESTRICTIONS
BIOASSAY
TOXICITY: REFERENCE ≥ TEST < LC50
TOXICITY: REFERENCE < TEST < LC50
TOXICITY: REFERENCE < TEST ≥ LC50
TOXICITY: REFERENCE ≥ TEST ≥ LC50
LAD
B15
MIXING
LAD
B17
NO RESTRICTIONS
RESTRICTIONS
WATER QUALITY CRITERIA
REFERENCE ≥ TEST < ACUTE CRITERION
REFERENCE < TEST < ACUTE CRITERION
TEST ≥ ACUTE CRITERION > REFERENCE
TEST ≥ REFERENCE ≥ ACUTE CRITERION
REFERENCE ≥ TEST ≥ ACUTE CRITERION
LAD
B7
MIXING
LAD
B9
NO RESTRICTIONS
RESTRICTIONS

Figure B2. Flowchart for decisionmaking for effluent water quality (number near LAD is paragraph discussing LAD)

when concern is primarily with contaminants for which water-quality criteria have been established (Table C2) and there is little concern about interactive effects of multiple contaminants. If the concern is primarily with chemicals for which water-quality criteria have not been established or there is concern about interactive effects of multiple contaminants, a biological approach is preferred.

DECISIONS FROM EFFLUENT CHEMICAL EVALUATIONS

B5. Chemical analyses of the effluent (modified elutriate) are evaluated in comparison to dissolved contaminant concentrations in a reference water which could be the receiving water or another appropriate local authority decision (LAD) reference water, and to acute water-quality criteria for contaminants for which criteria exist (Table C2). Acute criteria are maximum concentrations that should not be exceeded and are appropriate because of the transient nature of effluent water discharges into the receiving water. Contaminants for which criteria exist are evaluated separately from those for which criteria have not been established.

B6. When acute water-quality criteria exist for the contaminants of concern, five conditions are possible (Figure B2):

a. Concentrations of *all* dissolved contaminants in the test effluent are *less than or equal to* the reference water and *less than* the acute water-quality criterion for each contaminant (Table C2).

b. Concentration of *any* dissolved contaminant in the test is *greater than* in the reference water and *less than* the acute water-quality criterion (Table C2).

Conditions a and b lead to a DECISION OF NO RESTRICTIONS required to protect against degradation of the water column beyond existing reference site conditions.

c. Concentration of *any* dissolved contaminant in the test is *equal to or greater than* the reference water, and the reference water is *equal to or greater than* the acute water-quality criterion (Table C2).

d. Concentration of *any* dissolved contaminant in the test is *less than or equal to* the reference water and *equal to or greater than* the acute water-quality criterion (Table C2). Since dilution to the criterion cannot occur under conditions c and d (unless the receiving water for the discharge is not the reference water and is less than the criterion), conditions c or d lead to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the water column due to the proposed discharge. Some potentially appropriate restrictions are described in paragraphs 81-93.

e. Concentrations of any dissolved contaminant in the test is *equal to or greater than* the acute water quality criterion (Table C2) and the reference water is *less than* the acute water quality criterion. Since dilution to the criterion can occur (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion), this leads to a LOCAL AUTHORITY DECISION as discussed in paragraph B7.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER MIXING

B7. Under the conditions of subparagraph B6e, dilution will occur when the disposal site effluent enters the receiving water (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion). Consequently, mixing must be considered in order to scientifically assess the potential for effluent discharge impacts to occur. However, in some cases the local authority may choose to reach a decision without considering mixing by assessing test results in light of the increasing concern about potential contaminant impacts from the disposal site effluent discharge in direct relation to:

a. Number of contaminants (for which criteria have been established) exceeding reference concentrations.

b. Number of contaminants (with criteria) exceeding acute criteria.

c. Magnitude by which reference concentrations are exceeded.

d. Magnitude by which criteria are exceeded.

e. Toxicological importance of contaminants exceeding reference concentrations and/or acute criteria. Contaminants that can be objectively ranked in this manner are presented in Table C3.

f. Proportion of sediment sampling sites in the dredging area being evaluated that have test modified elutriates exceeding reference concentrations and/or acute criteria. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

In the case of subparagraph B6e, the local authority might choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount and are well below the acute criteria.* In the case of subparagraph B6e, the local authority might also choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference and the criteria by a substantial margin.* A decision for restrictions would be particularly appropriate in cases where the receiving water already exceeded the criterion, making dilution to the criterion impossible. Some potentially appropriate restrictions are described in paragraphs 81-93. If the local authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B9.

B8. *Commencement Bay area authorities have tentatively decided to make the local authority decision (LAD) discussed in paragraph B7 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B7 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. Number of contaminants above reference. If *25 percent or less* of the contaminants of concern (for which criteria have been established) exceed reference, there is cause for *low concern*. If *25 percent-90 percent* of the contaminants of concern with criteria exceed reference, there is cause for *moderate concern*. If *90 percent or more* of the contaminants of concern with criteria exceed reference, there is cause for *high concern*.

b. Number of contaminants above criteria. If *25 percent or less* of the contaminants of concern with criteria exceed the criteria, there is cause for *low concern*. If *25 percent-75 percent* of the contaminants of concern with criteria exceed the criteria, there is cause for *moderate concern*. If *75 percent or more* of the contaminants of concern with criteria exceed the criteria, there is cause for *high concern*.

c. Magnitude above reference. If the contaminant of concern (with a criterion) that exceeds reference by the greatest factor is *less than or equal to 25 times* reference concentration, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *25-100 times* reference concentration, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *100 or more times* reference concentration, there is cause for *high concern*.

d. Magnitude above criterion. If the contaminant of concern (with a criterion) that exceeds its criterion by the greatest factor is *less than or equal to 10 times* the criteria, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *10-100 times* the criteria, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *100 or more times* the criterion, there is cause for *high concern*.

e. Toxicological importance. If all contaminants of concern (with criteria) are *rank 1 or 2* in Table C3, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *rank 3 or 4* in Table C3, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *rank 5 or 6* in Table C3, there is cause for *high concern*. (Unranked contaminants of concern are cause for *moderate concern* unless there is additional evidence to reasonably warrant a different level of concern.)

f. Number of sampling sites. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated have any contaminant of concern (with a criterion) exceeding the reference or criterion, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites in the area being evaluated have any contaminant of concern (with a criterion) exceeding the reference or criterion, there is cause for *high concern*. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

Findings of *low concern in all factors*, a through f, lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. A finding of *high concern* in *any four of the six* factors, a through f, leads to a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 81-93. All other combinations of findings lead to a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B9.

DECISION FOR FURTHER EVALUATION: CONSIDER MIXING

B9. If the considerations of paragraph B7 lead to an evaluation of mixing, the local authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to the water-quality criteria are acceptable. Mixing zone calculation is described in paragraphs 31-33 and

Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing zone evaluation is discussed in paragraphs 34-36 and can result in:

a. A mixing zone of *acceptable* size and configuration within which the discharge will be diluted to less than the acute water quality criterion (Table C2). Acceptability of the mixing zone is determined in light of the considerations of paragraph 34 and paragraph B7 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water.

b. A mixing zone within which the discharge will be diluted to less than the acute water-quality criterion (Table C2) is of *unacceptable* size or configuration. Acceptability of the mixing zone is determined in light of the considerations of paragraph 34 and paragraph B7 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 81-93.

B10. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B9 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B9 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. A DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *acceptable* (paragraph 35) *and* there is cause for *low concern* in *any four of the six* factors in paragraph B8 considered at the edge of the mixing zone.

b. A DECISION OF RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *unacceptable* (paragraph 35) *or* there is cause for *moderate or high concern* in *any four of the six* factors in paragraph B8 considered at the edge of the mixing zone. Some potentially appropriate restrictions are described in paragraphs 81-93.

B11. When acute water-quality criteria do not exist for contaminants of concern, two conditions are possible (Figure B2):

a. Concentrations of *all* dissolved contaminants of concern in the test effluent are *less than or equal to* the receiving water (or reference water). This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the receiving water beyond existing reference site conditions.

b. Concentrations of *any* dissolved contaminant in the test effluent is *greater than* in the receiving water (or reference water). This leads to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: BIOASSAYS

B12. Under the conditions of subparagraph B11b there is no available information for determining the environmental importance of a contaminant that exceeds the reference concentration. This can be determined with bioassays. However, in some cases the local authority may choose to reach a decision without conducting bioassays by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to the factors listed in paragraph B7. In the case of subparagraph B11b, the local authority might choose, without conducting bioassays, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have a small number of contaminants exceeding the reference by a small amount.* Since there are no criteria, if bioassays are not considered necessary on the above basis, there is no "target concentration" for a mixing zone calculation. However, in addition to the contaminant considerations of paragraph B7, the effluent discharge should be subjectively assessed in light of the mixing zone considerations of paragraph 34 before a decision of no restrictions is reached. On the other hand, the local authority might choose, without conducting bioassays, to reach a DECISION FOR RESTRICTIONS required to protect contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 81-93. If the local authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by conducting bioassays as described in paragraph B14.

B13. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B12 using the quantitative approach described in paragraph B8. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Since there are no water-quality criteria for the contaminants presently under consideration, factors* b *and* d *are simply excluded from consideration, and the other factors evaluated as described in paragraph B8. If a* DECISION FOR FURTHER EVALUATION *is reached, bioassays must be conducted and evaluated as described in paragraph B14. Although conceptually similar approaches to interpreting test results in the absence of water-quality criteria could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B12 or its quantitation in the above manner since the guidance considerations may be complexly interactive. The approach described above is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

DECISIONS FROM EFFLUENT BIOLOGICAL EVALUATIONS

B14. From this point on, the evaluation of potential effluent impacts on the receiving water is biological. It is at this point that testing begins if a biological approach is initially chosen in paragraph B4 (Figure B2). Effluent (modified elutriate) bioassays can result in four possible conditions:

a. Toxicity of the test effluent (modified elutriate) to *all* species is *less than or equal to* the reference water and *less than* the LC50 (i.e., 50-percent toxicity is not reached in the test water). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water.

b. Toxicity of the test effluent to *any* species is *less than or equal to* the reference water and *equal to or greater than* the LC50 (i.e., at least 50-percent toxicity is reached in the test water). This leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. Some potential appropriate restrictions are described in paragraphs 81-93.

c. Toxicity of the test effluent to *any* species is *greater than* the reference water and *less than* the LC50, or

d. Toxicity of the test effluent to *any* spcies is *greater than* the reference water and *equal to or greater than* the LC50. (Therefore, dilution to the LC50 is possible if the receiving water for the discharge, which may or may not be the reference water, is less than the LC50.)

Conditions c and d lead to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER MIXING

B15. Under the conditions of subparagraph B14c or d, dilution will occur when the disposal site effluent discharge enters the receiving water (if the receiving water for the discharge, which may or may not be the reference water, is less than the LC50). Consequently, mixing must be considered in order to scientifically assess the potential for receiving water impacts to occur. However, in some cases the local authority may choose to reach a decision, without considering mixing, by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to:

a. Number of species bioassayed with the effluent with toxicity exceeding reference toxicity.

b. Magnitude of test toxicity.

c. Magnitude by which reference toxicity is exceeded.

d. Proportion of sediment sampling sites in the dredging area being evaluated that have effluents whose toxicity exceeds reference toxicity. (If a single composite sample from the dredging area is bioassayed, this factor drops from consideration.)

In the case of subparagraph B14c, the local authority may choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites are toxic to a low number of species and the toxicity only slightly exceeds reference toxicity and is well below 50 percent.* In the case of B14d, the authority may choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites are toxic to several species and the toxicity exceeds the reference toxicity and 50 percent by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 81-93. If the local authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B17.

B16. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B15 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B15 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. If the dredged material effluent produces greater toxicity than the reference material in *20 percent or less* of the test species, there is cause for *low concern*. If dredged material effluent toxicity exceeds reference toxicity in *20 percent-80 percent* of the test species, there is cause for *moderate concern*. If dredged material effluent toxicity exceeds reference toxicity in *80 percent or more* of the test species, there is cause for *high concern*.

b. If the dredged material effluent produces toxicity *20 percentage points* or less* above the control in all test species, there is cause for *low concern*. If dredged material effluent toxicity is *20-40 percentage points** above control toxicity in any species, there is cause for *moderate concern*. If dredged material effluent toxicity is *40 percentage points* or more* above control toxicity in any species, there is cause for *high concern*.

c. If the dredged material effluent produces toxicity in all species *less than or equal to two times* the reference material toxicity, there is cause for *low concern*. If dredged material effluent toxicity in any species is *2-40 times* reference toxicity, there is cause for *moderate concern*. If dredged material effluent toxicity in any species is *40 or more times* the reference toxicity, there is cause for *high concern*.

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* For example, if 2 of 100 control animals (2 percent) show toxicity, then at least 12 of 100 test animals (12 percent) would have to show toxicity in order for toxicity of the test sediment to be 10 percentage points above the control.

d. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated have effluent toxicity exceeding the reference toxicity, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites in the area being evaluated have effluent toxicity to any species exceeding the reference or criterion, there is cause for *high concern*. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

Findings of *low concern in all factors*, a through d, lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. A finding of *high concern* in *any three of the four factors* leads to a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraph 81-93. All other combinations of findings lead to a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B18.

DECISION FOR FURTHER EVALUATION: CONSIDER MIXING

B17. If the considerations of paragraph B15 lead to an evaluation of mixing, the local authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to less than the LC50 concentration are acceptable. Mixing zone calculation is described in paragraphs 31-33 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water*. Mixing zone evaluations as discussed in paragraphs 34-36 can result in:

a. A mixing zone of *acceptable* size and configuration within which the effluent discharge will be diluted to less than the LC50. Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph B15 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. (In the case of subparagraph B14c, the LC50 is not exceeded even without consideration of mixing, but if desired the mixing zone to dilute to some lower value, such as LC20, can be calculated.)

b. A mixing zone (within which the discharge will be diluted to less than the LC50) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph B15 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 81-93.

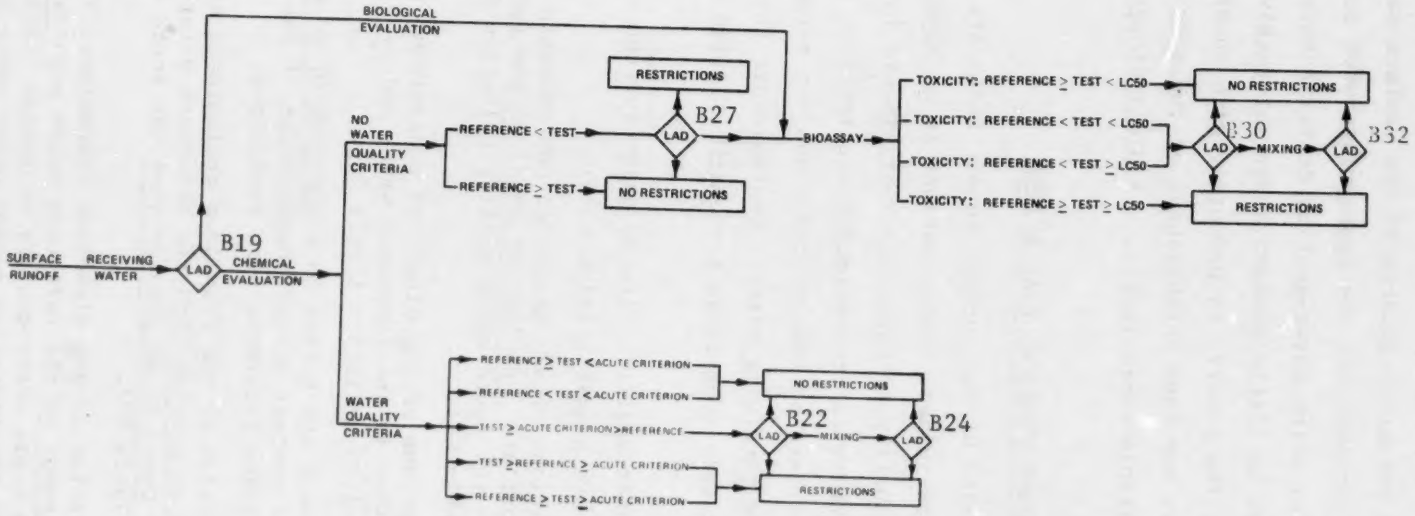
B18. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B17 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B17, or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. A DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *acceptable* (paragraph 35) *and* there is cause for *low concern* in *any three of the four* factors in paragraph B16 considered at the edge of the mixing zone.

b. A DECISION OF RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *unacceptable* (paragraph 35) *or* there is cause for *moderate or high* concern in *any two of the four* factors in paragraph B16 considered at the edge of the mixing zone. Some potentially appropriate restrictions are described in paragraphs 81-93.

Surface Runoff Quality Tests

B19. Concerns about contaminant impacts from surface runoff quality after the upland disposal site is filled and the dredged material begins to dry out have centered on short-term impacts in the receiving water during rainfall events. The decision points and the tests appropriate for determining potential impacts from surface runoff water are shown in Figure B3. This flowchart is similar to that for effluent water and the discussion of decision points is exactly the same. Surface runoff test results should always be compared to the quality of a reference surface water and to existing water-quality criteria. The reference surface water must be selected by LAD and could be the receiving water into which the disposal site surface runoff flows or it could be a surface water from another reference site. The



SURFACE RUNOFF
RECEIVING WATER
LAD
B19
CHEMICAL EVALUATION
BIOLOGICAL EVALUATION
NO WATER QUALITY CRITERIA
REFERENCE < TEST
REFERENCE ≥ TEST
LAD
B27
RESTRICTIONS
NO RESTRICTIONS
BIOASSAY
TOXICITY: REFERENCE ≥ TEST < LC50
TOXICITY: REFERENCE < TEST < LC50
TOXICITY: REFERENCE < TEST ≥ LC50
TOXICITY: REFERENCE ≥ TEST ≥ LC50
NO RESTRICTIONS
LAD
B30
MIXING
LAD
B32
RESTRICTIONS
WATER QUALITY CRITERIA
REFERENCE ≥ TEST < ACUTE CRITERION
REFERENCE < TEST < ACUTE CRITERION
TEST ≥ ACUTE CRITERION > REFERENCE
TEST ≥ REFERENCE ≥ ACUTE CRITERION
REFERENCE ≥ TEST ≥ ACUTE CRITERION
NO RESTRICTIONS
LAD
B22
MIXING
LAD
B24
RESTRICTIONS

Figure B3. Flowchart for decisionmaking for surface runoff water quality (number near LAD is paragraph discussing LAD)

local authority must decide whether to take a chemical or biological based approach to evaluating the potential impacts of the surface runoff on the receiving water. Chemical evaluations are appropriate when concern is primarily with contaminants for which water-quality criteria have been established (Table C2) and there is little concern about interactive effects of multiple contaminants. If the concern is primarily with chemicals for which water-quality criteria have not been established, or there is concern about interactive effects of multiple contaminants, a biological approach is preferred.

DECISIONS FROM SURFACE RUNOFF CHEMICAL EVALUATIONS

B20. Chemical analyses of the surface runoff tests are evaluated in comparison to dissolved contaminant concentrations in an appropriate reference water and to acute water-quality criteria for contaminants for which criteria exist (Table C2). Acute criteria are maximum concentrations that should not be exceeded and are appropriate because of the transient nature of surface runoff discharges into the receiving water. Contaminants for which criteria exist are evaluated separately from those for which criteria have not been established.

B21. When acute water-quality criteria exist for the contaminants of concern, five conditions are possible (Figure B3).

a. Concentrations of *all* dissolved contaminants in the test surface runoff are *less than or equal to* the reference water and *less than* the acute water-quality criterion for each contaminant (Table C2).

b. Concentrations of *any* dissolved contaminant in the test is *greater than* in the reference water and *less than* the acute water-quality criterion (Table C2).

Conditions a and b lead to a DECISION OF NO RESTRICTIONS required to protect against degradation of the water column beyond existing reference site conditions.

c. Concentration of *any* dissolved contaminant in the test is *equal to or greater than* the reference water and the reference water is *equal to or greater than* the acute water-quality criterion (Table C2).

d. Concentration of *any* dissolved contaminant in the test is *less than or equal to* the reference water and *equal to or greater than* the acute water-quality criterion (Table C2). Since dilution to the criterion cannot occur under conditions c and d (unless the receiving water for the discharge is not the reference water and is less than the criterion), this lead to a

DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the water column due to the proposed surface runoff discharge. Some potentially appropriate restrictions are described in paragraphs 81-92 and 94.

e. Concentrations of *any* dissolved contaminant in the test is *equal to or greater than* the acute water-quality criterion (Table C2) and the reference water is *less than* the acute water-quality criterion. Since dilution to the criterion can occur (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion), this leads to a LOCAL AUTHORITY DECISION as discussed in paragraph B22.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER MIXING

B22. Under the conditions of subparagraph B21e, dilution will occur when the disposal site surface runoff enters the receiving water (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion). Consequently, mixing must be considered in order to scientifically assess the potential for surface runoff discharge impacts to occur. However, in some cases the local authority may choose to reach a decision without considering mixing, by assessing test results in light of the increasing concern about potential contaminant impacts from the disposal site surface runoff discharge in direct relation to:

a. Number of contaminants (for which criteria have been established) exceeding reference concentrations.

b. Number of contaminants (with criteria) exceeding the acute criteria.

c. Magnitude by which reference concentrations are exceeded.

d. Magnitude by which criteria are exceeded.

e. Toxicological importance of contaminants exceeding reference concentrations and/or acute criteria. Contaminants that can be objectively ranked in this manner are presented in Table C3.

f. Proportion of sediment sampling sites in the dredging area being evaluated which have test surface runoff exceeding reference concentrations and/or acute criteria. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

In the case of subparagraph B21e, the local authority might choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount and are well below the acute criteria.* In the case of subparagraph 21e, the local authority might also choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference and the criteria by a substantial margin.* A decision for restrictions would be particularly appropriate in cases where the receiving water already exceeded the criterion, making dilution to the criterion impossible. Some potentially appropriate restrictions are described in paragraphs 81-92 and 94. If the local authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B24.

B23. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B22 using the following quantitative approach. This quantitation was selected for use when local goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B22 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. Number of contaminants above reference. If *25 percent or less* of the contaminants of concern (for which criteria have been established) exceed reference, there is cause for *low concern*. If *25 percent-90 percent* of the contaminants of concern with criteria exceed reference, there is cause for *moderate concern*. If *90 percent or more* of the contaminants of concern with criteria exceed reference, there is cause for *high concern*.

b. Number of contaminants above criteria. If *25 percent or less* of the contaminants of concern with criteria exceed the criteria, there is cause for *low concern*. If *25 percent-75 percent* of the contaminants of concern with criteria exceed the criteria, there is cause for *moderate concern*. If *75 percent or more* of the contaminants of concern with criteria exceed the criteria, there is cause for *high concern*.

c. Magnitude above reference. If the contaminant of concern (with a criterion) that exceeds reference by the greatest factor is *less than or equal to 25 times* reference concentration, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *25-100 times* reference concentration, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *100 or more times* reference concentration, there is cause for *high concern*.

d. Magnitude above criterion. If the contaminant of concern (with a criterion) that exceeds its criterion by the greatest factor is *less than or equal to 10 times* the criteria, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *10-100 times* the criteria, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *100 or more times* the criterion, there is cause for *high concern*.

e. Toxicological importance. If all contaminants of concern (with criteria) are *rank 1 or 2* in Table C3, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *rank 3 or 4* in Table C3, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *rank 5 or 6* in Table C3, there is cause for *high concern*. (Unranked contaminants of concern are cause for *moderate concern* unless there is additional evidence to reasonably warrant a different level of concern.)

f. Number of sampling sites. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated have any contaminant of concern (with a criterion) exceeding the reference or criterion, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites in the area being evaluated have any contaminant of concern (with a criterion) exceeding the reference or criterion, there is cause for *high concern*. (If a single composite sample from the dredging area is tested, this factor drops from consideration.)

Findings of *low concern in all factors*, a through f, lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts from surface runoff. A finding of *high concern* in *any four of the six factors*, a through f, leads to a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 81-92 and 94. All other combinations of findings lead to a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B25.

DECISION FOR FURTHER EVALUATION: CONSIDER MIXING

B24. If the considerations of paragraph B22 lead to an evaluation of mixing, the local authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to the water-quality criteria are acceptable. Mixing zone calculation is described in paragraphs 31-33 and Appendix D. *Note that mixing calculations must be based on the receiving waters for the discharge, which may or may not be the reference water.* Mixing zone evaluation as discussed in paragraphs 34-36 can result in:

a. A mixing zone of *acceptable* size and configuration within which the surface runoff will be diluted to less than the acute water-quality criterion (Table C2). Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph B22 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water.

b. A mixing zone within which the surface runoff will be diluted to less than the acute water-quality criterion (Table C2) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph B22 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 81-92 and 94.

B25. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B24 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B24 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. A DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *acceptable* (paragraph 35) *and* there is cause for *low concern* in *any four of the six factors* in paragraph B23 considered at the edge of the mixing zone.

b. A DECISION OF RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is unacceptable (paragraph 35) *or* there is cause for *moderate or high concern* in *any four of the six factors* in paragraph B23 considered at the edge of the mixing zone. Some potentially appropriate restrictions are described in paragraphs 81-92 and 94.

B26. When acute water-quality criteria do not exist for contaminants of concern, two conditions are possible (Figure B3):

a. Concentrations of *all* dissolved contaminants of concern in the test surface runoff are *less than or equal to* the reference water. This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the receiving water beyond existing reference site conditions.

b. Concentrations of *any* dissolved contaminant in the test surface runoff is *greater than* in the reference water. This leads to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: BIOASSAYS

B27. Under the conditions of subparagraph B26b there is no available information for determining the environmental importance of a contaminant which exceeds the reference concentration. This can be determined with bioassays. However, in some cases the local authority may choose to reach a decision, without conducting bioassays, by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to the factors listed in paragraph B22. In the case of subparagraph B26b, the local authority might choose, without conducting bioassays, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have a small number of contaminants exceeding the reference by a small amount.* Since there are no criteria, if bioassays are not considered necessary on the above basis, there is no "target concentration" for a mixing zone calculation. However, in addition to the contaminant considerations of paragraph B22, the surface runoff discharge should be subjectively assessed in light of the mixing zone considerations of paragraph 34 before a DECISION OF NO RESTRICTIONS is reached. On the other hand, the local authority might choose, without conducting bioassays, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 81-92 and 94. If the local authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by conducting bioassays as described in paragraph B29.

B28. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B27 using the quantitative approach described in paragraph B23. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Since there are no water-quality criteria for the contaminants presently under* *consideration, factors b and d are simply excluded from consideration, and the other factors evaluated as described in paragraph B23. If a DECISION FOR FURTHER EVALUATION is reached, bioassays must be conducted and evaluated as described in paragraph B29. Although conceptually similar approaches to interpreting test results in the absence of water-quality criteria could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B27 or its quantitation in the above manner since the guidance considerations may be complexly interactive. The approach described above is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual local authority decisions elsewhere.*

DECISIONS FROM SURFACE RUNOFF BIOLOGICAL EVALUATIONS

B29. From this point on, the evaluation of potential receiving water impacts is biological. It is at this point that testing begins if a biological approach is initially chosen in paragraph B19 (Figure B3). Surface runoff water bioassays can result in four possible conditions:

a. Toxicity of the test water (surface runoff) to *all* species is *less than or equal to* the reference water and *less than* the LC50 (i.e., 50-percent toxicity is not reached in the test water). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water.

b. Toxicity of the test water to *any* species is *less than or equal to* the reference water and *equal to or greater than* the LC50 (i.e., at least 50-percent toxicity is reached in the test water). This leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 81-92 and 94.

c. Toxicity of the test water to *any* species is *greater than* the reference water, and *less than* the LC50, or

d. Toxicity of the test water to *any* spcies is *greater than* the reference water and *equal to or greater than* the LC50. (Therefore, dilution to the LC50 is possible if the receiving water for the discharge, which may or may not be the reference water, is less than the LC50).

Conditions c and d lead to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER MIXING

B30. Under the conditions of subparagraph B29c or d, dilution will occur when the disposal site surface runoff enters the receiving water (if the receiving water for the discharge, which may or may not be the reference water, is less than the LC50). Consequently, mixing must be considered in order to scientifically assess the potential for receiving water impacts to occur. However, in some cases the local authority may choose to reach a decision, without considering mixing, by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to:

a. Number of species bioassayed with surface runoff with toxicity exceeding reference toxicity.

b. Magnitude of test toxicity.

c. Magnitude by which reference toxicity is exceeded.

d. Proportion of sediment sampling sites in the dredging area being evaluated which have surface runoff whose toxicity exceeds reference toxicity. (If a single composite sample from the dredging area is bioassayed, this factor drops from consideration.)

In the case of subparagraph B29c, the local authority may choose, without considering mixing, to reach a DECISON OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites are toxic to a low number of species and the toxicity only slightly exceeds reference toxicity and is well below 50 percent.* In the case of subparagraph B29d the authority may choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites are toxic to several species and the toxicity exceeds the reference toxicity and 50 percent by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 81-92 and 94. If the local authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B32.

B31. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B30 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its* *quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B30 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. If the dredged material surface runoff produces greater toxicity than the reference material in *20 percent or less* of the test species, there is cause for *low concern*. If dredged material surface runoff toxicity exceeds reference toxicity in *20 percent-80 percent* of the test species, there is cause for *moderate concern*. If dredged material surface runoff toxicity exceeds reference toxicity in *80 percent or more* of the test species, there is cause for *high concern*.

b. If the dredged material surface runoff produces toxicity in all test species *20 percentage points* or less* above the control, there is cause for *low concern*. If dredged material surface runoff toxicity in any test species is *20-40 percentage points** above control toxicity, there is cause for *moderate concern*. If dredged material surface runoff toxicity in any test species is *40 percentage points* or more* above control toxicity, there is cause for *high concern*.

c. If the dredged material surface runoff produces toxicity in all species *less than or equal to two times* the reference material toxicity, there is cause for *low concern*. If dredged material surface runoff toxicity in any species is *2-40 times* reference toxicity, there is cause for *moderate concern*. If dredged material surface runoff toxicity in any species is *40 or more times* the reference toxicity, there is cause for *high concern*.

d. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated have surface runoff toxicity to any species exceeding the reference toxicity, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites in the area being evaluated have surface runoff toxicity to any species exceeding the reference toxicity, there is cause for *high concern*.

Findings of *low concern in all factors*, a through d, lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. A finding of *high concern* in two or more factors leads to a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 81-92 and 94. All other combinations of findings lead to a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B33.

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* For example, if 2 of 100 control animals (2 percent) show toxicity, then at least 22 of 100 test animals (22 percent) would have to show toxicity in order for toxicity of the test sediment to be 20 percentage points above the control.

DECISION FOR FURTHER EVALUATION: CONSIDER MIXING

B32. If the considerations of paragraph B30 lead to an evaluation of mixing, the local authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to less than the LC50 concentration are acceptable. Mixing zone calculation is described in paragraphs 31-33 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing zone evaluations as discussed in paragraphs 34-36 can result in:

a. A mixing zone of *acceptable* size and configuration within which the surface runoff will be diluted to less than the LC50. Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph B30 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. (In the case of subparagraph B29c, the LC50 is not exceeded even without consideration of mixing, but if desired, the mixing zone to dilute to some lower value, such as LC20, can be calculated.)

b. A mixing zone (within which the surface runoff will be diluted to less than the LC50) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph B30 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 81-92 and 94.

B33. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B31 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B31 or its quantitation in the following manner since the guidance* *considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. A DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *acceptable* (paragraph 35) *and* there is cause for *low concern* in *any three of the four* factors in paragraph B31 considered at the edge of the mixing zone.

b. A DECISION OF RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *unacceptable* (paragraph 35) *or* there is cause for *moderate or high concern* in *any two of the four* factors in paragraph B31 considered at the edge of the mixing zone. Some potentially appropriate restrictions are described in paragraphs 81-92 and 94.

Leachate Quality Tests

B34. Leachate quality tests will indicate the potential of contaminants to move through and from a dredged material. Leachate quality evaluation has been divided into three parts: impact of seepage through a dike into a receiving water body (Figure B4), a impact of leachate on drinking water (Figure B4), and impact on nonpotable ground water (Figure B5). Test results should always be compared to the quality of an appropriate reference water. The local authority must select a reference surface water such as the receiving water adjacent to the disposal site or another reference (background) surface water. Water-quality criteria (Table C2) should be used to compare leachate test results to make a decision on relative biological impacts. In addition, the local authority must select a reference ground water such as the ground water under the disposal site or another reference (background) to compare to leachate test results. Drinking water-quality standards (Table C4) should be used to compare leachate test results to make a decision on relative human health effects. If drinking water-quality standards do not exist, then leachate test results are compared to the appropriate reference water. The selection of each of these reference waters by the Commence Bay area authorities is governed by the overall goal established by the local authority for the area as discussed in paragraph 70.

LEACHATE SEEPAGE INTO A RECEIVING WATER BODY

B35. The local authority must decide whether to take a chemical or biological based approach to evaluating the potential impacts of the leachate seepage on the receiving water. Chemical evaluations are appropriate when concern is primarily with contaminants for which water-quality criteria have been established (Table C2) and there is little concern about interactive effects of multiple contaminants. If the concern is primarily with chemicals for which water-quality criteria have not been established or if there is concern about interactive effects of multiple contaminants, a biological approach is preferred.

DECISIONS FROM LEACHATE SEEPAGE CHEMICAL EVALUATIONS

B36. Chemical analyses of the leachate are evaluated in comparison to dissolved contaminant concentrations in a reference water and to chronic water-quality criteria for contaminants for which criteria exist (Table C2). The 24-hr average water concentration should not exceed the chronic criterion. Chronic criteria are appropriate because of the long-term nature of leachate seepage into the receiving water. Contaminants for which criteria exist are evaluated separately from those for which criteria have not been established.

B37. When chronic water quality criteria exist for the contaminants of concern, five conditions are possible (Figure B4).

a. Concentrations of *all* dissolved contaminants in the test leachate are *less than or equal to* the reference water and *less than* the chronic water-quality criterion for each contaminant (Table C2).

b. Concentration of *any* dissolved contaminant in the test is *greater than* in the reference water and *less than* the chronic water-quality criterion (Table C2).

Conditions *a* and *b* lead to a *DECISION OF NO RESTRICTIONS* required to protect against degradation of the water column beyond existing reference site conditions.

c. Concentrations of *any* dissolved contaminant in the test is *equal to or greater than* the reference water, and the reference water is *equal to or greater than* the chronic water-quality criterion (Table C2).

d. Concentration of *any* dissolved contaminant in the test is *less than or equal to* the reference water and *equal to or greater than* the chronic water-quality criterion (Table C2). Since dilution to the criterion cannot occur under conditions *c* and *d* (unless the receiving water for the discharge is not the reference water and is less than the criterion), they lead to

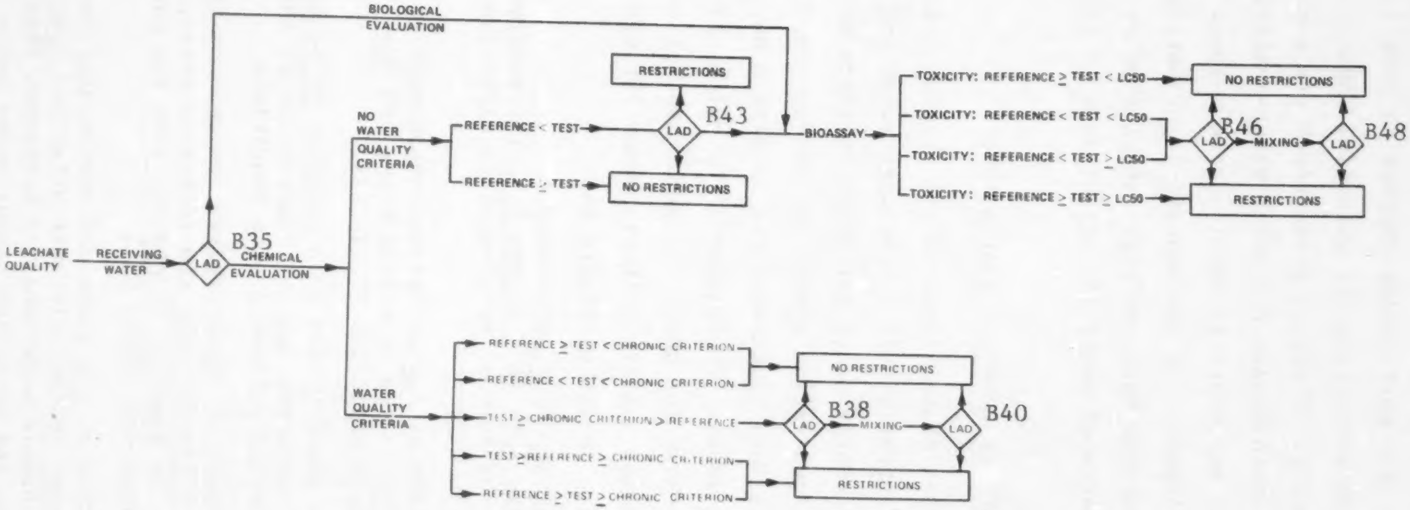
LEACHATE QUALITY
RECEIVING WATER
LAD
B35
BIOLOGICAL EVALUATION
CHEMICAL EVALUATION
NO WATER QUALITY CRITERIA
REFERENCE < TEST
REFERENCE ≥ TEST
RESTRICTIONS
LAD
B43
NO RESTRICTIONS
BIOASSAY
TOXICITY: REFERENCE ≥ TEST < LC50
TOXICITY: REFERENCE < TEST < LC50
TOXICITY: REFERENCE < TEST ≥ LC50
TOXICITY: REFERENCE ≥ TEST ≥ LC50
NO RESTRICTIONS
LAD
B46
MIXING
LAD
B48
RESTRICTIONS
WATER QUALITY CRITERIA
REFERENCE ≥ TEST < CHRONIC CRITERION
REFERENCE < TEST < CHRONIC CRITERION
TEST ≥ CHRONIC CRITERION > REFERENCE
TEST ≥ REFERENCE ≥ CHRONIC CRITERION
REFERENCE ≥ TEST ≥ CHRONIC CRITERION
NO RESTRICTIONS
LAD
B38
MIXING
LAD
B40
RESTRICTIONS

Figure B4. Flowchart for decisionmaking for leachate seepage quality impact to receiving water (number near LAD is paragraph discussing LAD)

a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the water column due to leachate from the proposed discharge. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95.

e. Concentrations of *any* dissolved contaminant in the test is *equal to or greater than* the chronic water-quality criterion (Table C2), and the reference water is *less than* the chronic water-quality criterion. Since dilution to the criterion can occur (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion), this leads to a LOCAL AUTHORITY DECISION as discussed in paragraph B38.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER MIXING

B38. Under the conditions of subparagraph B37e, dilution will occur when the disposal site leachate enters the receiving water (if the receiving water for the discharge, which may or may not be the reference water, is less than the criterion). Consequently, mixing must be considered in order to scientifically assess the potential for leachate impacts to occur. However, in some cases the local authority may choose to reach a decision, without considering mixing, by assessing test results in light of the increasing concern about potential contaminant impacts from the disposal site leachate in direct relation to:

a. Number of contaminants (for which criteria have been established) exceeding reference concentration.

b. Number of contaminants (with criteria) exceeding chronic criteria.

c. Magnitude by which reference concentrations and/or chronic criteria are exceeded.

d. Magnitude by which criteria are exceeded.

e. Toxicological importance of contaminants exceeding reference concentrations and/or chronic criteria. Contaminants that can be objectively ranked in this manner are presented in Table C3.

f. Proportion of sediment sampling sites in the dredging area being evaluated that have test leachate exceeding reference concentrations and/or chronic criteria. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

In the case of subparagraph B37e, the local authority might choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have only a small number of contaminants of* *relatively low toxicological concern exceeding the reference by a small amount and are well below the chronic criteria.* In the case of subparagraph B37e, the local authority might also choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference and the criteria by a substantial margin.* A DECISION FOR RESTRICTIONS would be particularly appropriate in cases where the receiving water already exceeded the criterion, making dilution to the criterion impossible. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95. If the local authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B40.

B39. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B38 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B38, or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. Number of contaminants above reference. If *25 percent or less* of the contaminants of concern (for which criteria have been established) exceed reference, there is cause for *low concern*. If *25 percent-90 percent* of the contaminants of concern with criteria exceed reference, there is cause for *moderate concern*. If *90 percent or more* of the contaminants of concern with criteria exceed reference, there is cause for *high concern*.

b. Number of contaminants above criteria. If *25 percent or less* of the contaminants of concern with criteria exceed the criteria, there is cause for *low concern*. If *25 percent-*

75 percent of the contaminants of concern with criteria exceed the criteria, there is cause for *moderate concern*. If *75 percent or more* of the contaminants of concern with criteria exceed the criteria, there is cause for *high concern*.

c. Magnitude above reference. If the contaminant of concern (with a criterion) present in the highest concentration is *less than or equal to 25 times* reference concentration, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *25-100 times* reference concentration, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *100 or more times* reference concentration, there is cause for *high concern*.

d. Magnitude above criterion. If the contaminant of concern (with a criterion) present in the highest concentration is *less than or equal to 10 times* the criteria, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *10-100 times* the criteria, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *100 or more times* the criterion, there is cause for *high concern*.

e. Toxicological importance. If all contaminants of concern (with criteria) are *rank 1 or 2* in Table C3, there is cause for *low concern*. If any contaminant of concern (with a criterion) is *rank 3 or 4* in Table C3, there is cause for *moderate concern*. If any contaminant of concern (with a criterion) is *rank 5 or 6* in Table C3, there is cause for *high concern*. (Unranked contaminants of concern are cause for *moderate concern* unless there is additional evidence to reasonably warrant a different level of concern.)

f. Number of sampling sites. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated have any contaminant of concern (with a criterion) in the leachate exceeding the reference or criterion, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites in the area being evaluated have any contaminant of concern (with a criterion) in the leachate exceeding the reference or criterion, there is cause for *high concern*. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

Findings of *low concern in all factors*, a through f, lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. A finding of *high concern* in *any four of the six* factors, a through f, leads to a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95. All other combinations of findings lead to a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B40.

DECISION FOR FURTHER EVALUATION: CONSIDER MIXING

B40. If the considerations of paragraph B38 lead to an evaluation of mixing, the local authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to the water-quality criteria are acceptable. Mixing zone calculation is described in paragraphs 31-33 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing zone evaluation as discussed in paragraphs 34-36 can result in:

a. A mixing zone of *acceptable* size and configuration within which the discharge will be diluted to less than the chronic water quality criterion (Table C2). Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B38 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water.

b. A mixing zone within which the discharge will be diluted to less than the chronic water-quality criterion (Table C2) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 35 and paragraph B38 evaluated at the edge of the mixing zone. This leads to a DECISION OF RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95.

B41. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B40 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B40 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. A DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *acceptable* (paragraph 35) *and* there is cause for *low concern* in *any four of the six* factors in paragraph B39 considered at the edge of the mixing zone.

b. A DECISION OF RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *unacceptable* (paragraph 35) *or* there is cause for *moderate or high concern* in *any four of the six* factors in paragraph B39 considered at the edge of the mixing zone. Some potentially appropriate restrictions are described in paragraphs 81-92 and 94.

B42. When chronic water quality criteria do not exist for contaminants of concern, two conditions are possible (Figure B4):

a. Concentrations of *all* dissolved contaminants of concern in the test leachate are *less than or equal to* the receiving water (or reference water). This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the receiving water beyond existing reference site conditions.

b. Concentrations of *any* dissolved contaminant in the test leachate is *greater than* in the receiving water (or reference water). This leads to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER BIOASSAYS

B43. Under the conditions of subparagraph B42b, there is no available information for determining the environmental importance of a contaminant that exceeds the reference concentration. This can be determined with bioassays. However, in some cases the local authority may choose to reach a decision, without conducting bioassays, by assessing test results in light of the increasing concern about potential contaminant impacts in the recieving water in direct relation to the factors listed in paragraph B38. In the case of subparagraph B42b, the local authority might also choose, without conducting bioassays, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites have a small number of contaminants exceeding the reference by a small amount.* Since there are no criteria, if bioassays are not considered necessary on the above basis, there is no "target concentration" for a mixing zone calculation. However, in addition to the contaminant considerations of paragraph B38, the leachate seepage should be subjectively assessed in light of the mixing zone considerations of paragraph 34 before a decision of no restrictions is reached. On the other hand, the local authority might choose, without conducting bioassays, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites have several contaminants exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 81-92 and 95. If the local authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by conducting bioassays as described in paragraph B45.

B44. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B43 using the quantitative approach described in paragraph B39. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Since there are no water-quality criteria for the contaminants presently under consideration, factors b and d are simply excluded from consideration, and the other factors evaluated as described in paragraph B39. If a* DECISION FOR FURTHER EVALUATION *is reached, bioassays must be conducted and evaluated as described in paragraph B45. Although conceptually similar approaches to interpreting test results in the absence of water-quality criteria could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B43 or its quantitation in the above manner since the guidance considerations may be complexly interactive. The approach described above is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

DECISIONS FROM LEACHATE BIOLOGICAL EVALUATIONS

B45. From this point on, the evaluation of potential receiving water impacts is biological. It is at this point that testing begins if a biological approach is initially chosen in paragraph B35 (Figure B4). Leachate bioassays can result in four possible conditions:

a. Toxicity of the test water (leachate) to *all* species is *less than or equal to* the reference water (receiving water) and *less than* the LC50 (i.e., 50-percent toxicity is not reached in the test water). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water.

b. Toxicity of the test water to *any* species is *less than or equal to* the reference water and *equal to or greater than* the LC50 (i.e., at least 50-percent toxicity is reached in the test water). This leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. Some potential appropriate restrictions are described in paragraphs 81-92 and 95.

c. Toxicity of the test water to *any* species is *greater than* the reference water and *less than* the LC50, or

d. Toxicity of the test water to *any* spcies is *greater than* the reference water and *equal to or greater than* the LC50. (Therefore, dilution to the LC50 is possible if the receiving water for the discharge, which may or may not be the reference water, is less than the LC50.)

Conditions c and d lead to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER MIXING

B46. Under the conditions of subparagraph B45c or d, dilution will occur when the disposal site effluent discharge enters the receiving water (if the receiving water for the discharge, which may or may not be the reference water, is less than the LC50). Consequently, mixing must be considered in order to scientifically assess the potential for receiving water impacts to occur. However, in some cases the local authority may choose to reach a decision, without considering mixing, by assessing test results in light of the increasing concern about potential contaminant impacts in the receiving water in direct relation to:

a. Number of species bioassayed with the leachate with toxicity exceeding reference toxicity.

b. Magnitude of test toxicity.

c. Magnitude by which reference toxicity is exceeded.

d. Proportion of sediment sampling sites in the dredging area being evaluated that have leachate whose toxicity exceeds reference toxicity. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

In the case of subparagraph B45c the local authority may choose, without considering mixing, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from only a few sites are toxic to a low number of species and the toxicity only slightly exceeds reference toxicity and is well below 50 percent.* In the case of subparagraph B45d, the authority may choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the receiving water. *This may be appropriate if samples from a number of sites are toxic to several species and the toxicity exceeds the reference toxicity and 50 percent by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 81-92 and 95. If the local authority desires to fully evaluate the potential for receiving water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B48.

B47. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B46 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B46 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. If the dredged material leachate produces greater toxicity than the reference material in *20 percent or less* of the test species, there is cause for *low concern*. If dredged material leachate toxicity exceeds reference toxicity in *20 percent-80 percent* of the test species, there is cause for *moderate concern*. If dredged material leachate toxicity exceeds reference toxicity in *80 percent or more* of the test species, there is cause for *high concern*.

b. If the dredged material leachate produces toxicity in all test species *20 percentage points* or less* above the control, there is cause for *low concern*. If dredged material leachate toxicity in any test species is *20-40 percentage points** above control toxicity, there is cause for *moderate concern*. If dredged material leachate toxicity in any test species is *40 percentage points* or more* above control toxicity, there is cause for *high concern*.

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* For example, if 2 of 100 control animals (2 percent) show toxicity, then at least 12 of 100 test animals (12 percent would have to show toxicity in order for toxicity of the test sediment to be 10 percentage points above the control.

c. If the dredged material leachate produces toxicity in all species *less than or equal to two times* the reference material toxicity, there is cause for *low concern*. If dredged material leachate toxicity in any species is *2-40 times* reference toxicity, there is cause for *moderate concern*. If dredged material leachate toxicity in any species is *40 or more times* the reference toxicity, there is cause for *high concern*.

d. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated have leachate toxicity exceeding the reference toxicity, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites in the area being evaluated have leachate toxicity exceeding the reference toxicity, there is cause for *high concern*.

Findings of *low concern in all factors*, a through d, lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the water column. A finding of *high concern* in any three of the four factors leads to a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the water column. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95. All other combinations of findings lead to a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B49.

DECISION FOR FURTHER EVALUATION: CONSIDER MIXING

B48. If the consideration of paragraph B46 lead to an evaluation of mixing, the local authority must decide whether the size and configuration of the mixing zone required to dilute the discharge to less than the LC50 concentration are acceptable. Mixing zone calculation is described in paragraphs 31-33 and Appendix D. *Note that mixing calculations must be based on the receiving water for the discharge, which may or may not be the reference water.* Mixing zone evaluations as discussed in paragraphs 34-36 can result in:

a. A mixing zone of *acceptable* size and configuration within which the leachate will be diluted to less than the LC50. Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph B46 evaluated at the edge of the mixing zone. This leads to a DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. (In the case of subparagraph B45c, the LC50 is not exceeded even without consideration of mixing, but if desired, the mixing zone to dilute to some lower value, such as LC20, can be calculated.)

b. A mixing zone (within which the leachate will be diluted to less than the LC50) that is of *unacceptable* size and/or configuration. Acceptability of the mixing zone is determined in light of the considerations in paragraph 34 and paragraph B46 evaluated at the edge of the mixing zone. This leads to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts in the receiving water. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95.

B49. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B48 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) required the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B48 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. A DECISION OF NO RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *acceptable* (paragraph 35) *and* there is cause for *low concern* in *any three of the four* factors in paragraph B47 considered at the edge of the mixing zone.

b. A DECISION OF RESTRICTIONS required to protect against possible contaminant impacts in the water column is reached if the mixing zone is *unacceptable* (paragraph 35) *or* there is cause for *moderate or high concern* in *any two of the four* factors in paragraph B47 considered at the edge of the mixing zone. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95.

DECISIONS FOR LEACHATE INTO DRINKING WATER

B50. When drinking water standards do not exist for contaminants of concern, two conditions are possible (Figure B5):

a. Leachate concentrations of *all* contaminants are *less than or equal to* the reference ground water. This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the ground water beyond existing reference ground-water conditions.

b. Leachate concentrations of *any* contaminant are *greater than* the reference ground water. This leads to a DECISION FOR

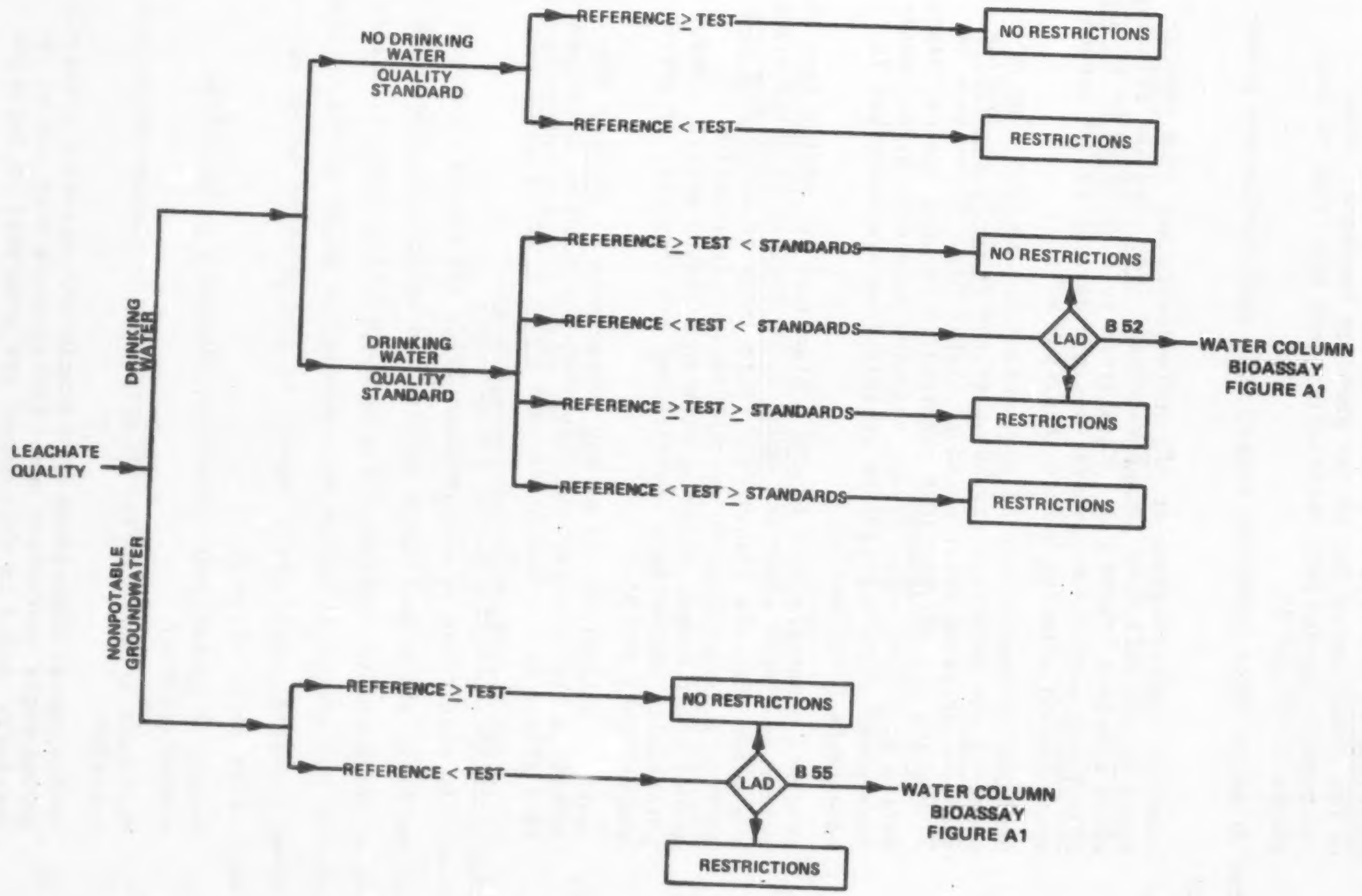
LEACHATE QUALITY
DRINKING WATER
NONPOTABLE GROUNDWATER
NO DRINKING WATER QUALITY STANDARD
DRINKING WATER QUALITY STANDARD
REFERENCE ≥ TEST
REFERENCE < TEST
NO RESTRICTIONS
RESTRICTIONS
REFERENCE ≥ TEST < STANDARDS
REFERENCE < TEST < STANDARDS
REFERENCE ≥ TEST ≥ STANDARDS
REFERENCE < TEST ≥ STANDARDS
NO RESTRICTIONS
LAD
B 52
WATER COLUMN BIOASSAY FIGURE A1
RESTRICTIONS
RESTRICTIONS
REFERENCE ≥ TEST
REFERENCE < TEST
NO RESTRICTIONS
LAD
B 55
WATER COLUMN BIOASSAY FIGURE A1
RESTRICTIONS

Figure B5. Flowchart for decisionmaking for leachate impacts to drinking water or nonpotable ground water (number near LAD is paragraph discussing LAD)

RESTRICTIONS required to protect against contaminant impact in the ground water due to the proposed leachate. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95.

B51. When drinking water standards exist, four test results are possible (Figure B5):

a. Leachate concentrations of *all* contaminants are *less than or equal to* the reference ground water and *less than* the drinking water standard (Table C4). This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of ground water beyond existing reference ground water.

b. Leachate concentrations of *any* contaminant is *less than or equal to* the reference ground water and *equal to or greater than* the drinking water standard (Table C4). This leads to a DECISION FOR RESTRICTIONS required to protect against degradation of ground water beyond existing reference ground water. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95.

c. Leachate concentrations of *any* contaminant is *greater than* the reference ground water and *equal to or greater than* the drinking water standard (Table C4). This leads to a DECISION FOR RESTRICTIONS required to protect against degradation of ground water beyond existing reference ground water. Some potentially appropriate restrictions are described in paragraphs 82-91 and 95.

d. Leachate concentrations of *any* contaminant is *greater than* reference ground water and *less than* the drinking water standard (Table C4). This leads to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS

B52. Under the conditions of subparagraph B51d, the reference ground water selected may be of exceptional high quality and contain extremely low concentrations of contaminants, substantially below drinking water standards. The local authority may choose to assess test results in light of the increasing concern about potential contaminant impacts to ground water beyond existing reference ground water in relation to:

a. Number of contaminants exceeding reference ground-water concentrations.

b. Magnitude by which reference ground-water concentrations are exceeded.

c. Toxicological importance of contaminants exceeding reference ground-water concentrations. Contaminants that can be objectively ranked in this manner are presented in Table C3.

d. Proportion of sediment sampling sites in the area being evaluated that have test leachates exceeding reference ground-water concentrations. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

The local authority might choose to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the ground water. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount and are well below drinking water standards.* In contrast, the local authority might choose to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts in the ground water. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference ground water and approaching the drinking water standards.* Some potentially appropriate restrictions are described in paragraphs 81-92 and 95.

B53. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B52 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B52 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay authorities and should not be construed as final Commencement Bay guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. Number of contaminants above reference. If *25 percent or less* of the contaminants of concern (for which standards have been established) exceed reference, there is cause for *low concern*. If *25 percent-90 percent* of the contaminants of concern with standards exceed reference, there is cause for *moderate concern*. If *90 percent or more* of the contaminants of concern with standards exceed reference, there is cause for *high concern*.

b. Number of contaminants above standards. If *25 percent or less* of the contaminants of concern with standards exceed the standards, there is cause for *low concern*. If *25 percent-75 percent* of the contaminants of concern with standards exceed the standards, there is cause for *moderate concern*. If

75 percent or more of the contaminants of concern with standards exceed the standards, there is cause for *high concern*.

c. *Magnitude above reference.* If the contaminant of concern (with a standard) present in the highest concentration is *less than or equal to 25 times* reference concentration, there is cause for *low concern*. If any contaminant of concern (with a standard) is *25-100 times* reference concentration, there is cause for *moderate concern*. If any contaminant of concern (with a standard) is *100 or more times* reference concentration, there is cause for *high concern*.

d. *Magnitude above standard.* If the contaminant of concern (with a standard) present in the highest concentration is *less than or equal to 10 times* the standards, there is cause for *low concern*. If any contaminant of concern (with a standard) is *10-100 times* the standards, there is cause for *moderate concern*. If any contaminant of concern (with a standard) is *100 or more times* the standard, there is cause for *high concern*.

e. *Toxicological importance.* If all contaminants of concern (with standards) are *rank 1 or 2* in Table C3, there is cause for *low concern*. If any contaminant of concern (with a standard) is *rank 3 or 4* in Table C3, there is cause for *moderate concern*. If any contaminant of concern (with a standard) is *rank 5 or 6* in Table C3, there is cause for *high concern*. (Unranked contaminants of concern are cause for *moderate concern* unless there is additional evidence to reasonably warrant a different level of concern.)

f. *Number of sampling sites.* If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated have any contaminant of concern (with a standard) in the leachate exceeding the reference or standard, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites in the area being evaluated have any contaminant of concern (with a standard) in the leachate exceeding the reference or standard, there is cause for *high concern*. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

Findings of *low concern in all factors*, a through f, lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the ground water. A finding of *moderate or high concern* in *four or more factors*, leads to a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the ground water. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95. All other combinations of findings lead to a DECISION FOR FURTHER EVALUATION by considering a water column bioassay as discussed in paragraph B57.

DECISIONS FOR LEACHATE INTO NONPOTABLE GROUND WATER

B54. Leachate test results should be compared to an appropriate reference ground water. Tests can result in:

a. Leachate concentrations of *all* contaminants are *less than or equal to* the reference ground water. This leads to a DECISION OF NO RESTRICTIONS required to protect against degradation of the ground water beyond existing reference ground-water conditions.

b. Leachate concentrations of *any* contaminants are *greater than* the reference ground water. This leads to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER BIOASSAYS

B55. Under the conditions of subparagraph B54b, the local authority may choose to assess test results in light of the increasing concern about potential contaminant impacts to ground water beyond existing reference ground water in relation to:

a. Number of contaminants exceeding reference ground water.

b. Magnitude by which reference ground-water concentrations are exceeded.

c. Toxicological importance of contaminants exceeding reference ground-water concentrations. Contaminants which can be objectively ranked in this manner are presented in Table C3.

d. Proportion of sediment sampling sites in the area being evaluated that have test leachates exceeding reference ground-water concentrations. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

The local authority might choose to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on the ground water. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount.* In contrast, the local authority might choose to reach a DECISION FOR RESTRICTION required to protect against contaminant impacts on the ground water. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference ground water.* Some potentially appropriate restrictions are described in paragraphs 81-92 and 95. If the local authority desires to fully evaluate the potential for ground-water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering bioassays as discussed in paragraph B57.

B56. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B55 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B55 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. Number of contaminants. If *25 percent or less* of the contaminants of concern exceed reference, there is cause for *low concern*. If *25 percent-90 percent* of the contaminants of concern exceed reference, there is cause for *moderate concern*. If *90 percent or more* of the contaminants of concern exceed reference, there is cause for *high concern*.

b. Magnitude above reference. If test concentration is *less than or equal to 25 times* reference concentration, there is cause for *low concern*. If any contaminant of concern is *greater than 25 and up to 100 times* reference concentration, there is cause for *moderate concern*. If any contaminant of concern is *100 or more times* reference concentration, there is cause for *high concern*.

c. Toxicological importance. If the contaminants of concern are *rank 1 or 2* in Table C3, there is cause for *low concern*. If any contaminant of concern is *rank 3 or 4* in Table C3, there is cause for *moderate concern*. If any contaminant of concern is *rank 5 or 6* in Table C3, there is cause for *high concern*. (Unranked contaminants of concern are cause for *moderate concern* unless there is additional evidence to reasonably warrant a different level of concern.)

d. Number of sampling sites. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated have any contaminant of concern exceeding the reference, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites in the area being evaluated have any contaminant of concern exceeding the reference, there is cause for *high concern*. (If a single composite sample from the dredging area is analyzed, this factor drops from consideration.)

Findings of *low concern in all factors*, a through d, lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts in the ground water. A finding of *moderate or high concern* in *two or more factors* leads to a DECISION OF RESTRICTIONS required to protect against contaminant impacts in the ground water. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95. All other combinations of findings lead to a DECISION FOR FURTHER EVALUATION by considering a water column bioassay as discussed in paragraph B57.

DECISION FOR FURTHER EVALUATION: BIOASSAYS

B57. Water column bioassays of the test leachate can give two possible results:

a. Toxicity of the test leachate to all species is *less than 50 percent* of the reference ground water. This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on the ground water.

b. Toxicity of the test leachate to any species is *equal to or greater than 50 percent* of the reference ground water. This leads to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: RESTRICTIONS/CONSIDER MIXING

B58. In the case of subparagraph B57b, the local authority might choose, without considering mixing, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts on nonpotable ground water. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95. If the local authority desires to fully evaluate the potential for nonpotable ground-water impacts to occur, it will reach a DECISION FOR FURTHER EVALUATION by considering mixing as discussed in paragraph B60.

B59. *Commencement Bay area authorities have tentatively decided not to consider mixing when a nonpotable ground water resurfaces into a water body. Consequently, a* DECISION FOR RESTRICTIONS *will be reached for water column bioassay results described in paragraph B57b. Commencement Bay area authorities have tentatively decided to consider the benthic impacts of a nonpotable ground water resurfacing through sediments of the receiving water body. As ground water passes through the sediments, contaminants may be adsorbed to the sediments, resulting in accumulation of ground-water contaminants. The impact of these contaminants on benthic organisms could be evaluated from the results of a benthic bioassay on the originally dredged sediment assuming a worst case of all the contaminants leaching into the ground water and then being accumulated in the sediments of the receiving water body. Decisions for this* *scenario are similar to the benthic impacts of aquatic disposal that were discussed in Appendix A (Figure A2 and paragraphs A19-A23).*

DECISION FOR FURTHER EVALUATION: CONSIDER MIXING

B60. Consideration of a mixing zone when nonpotable ground water emerges into a water body such as a river or bay can give two possible results:

- a. A mixing zone of *acceptable* size and/or configuration (paragraph 34) within which the nonpotable ground-water discharge will be diluted to *less than* an LC50. This leads to a DECISION FOR NO RESTRICTIONS required to protect against possible contaminant impacts on the receiving water body.
- b. A mixing zone of *unacceptable* size and/or configuration (paragraph 34) within which the nonpotable ground-water discharge will not be diluted and will still be *equal to or greater than* the LC50. This leads to a DECISION FOR RESTRICTIONS required to protect against degradation of the receiving water body. Some potentially appropriate restrictions are described in paragraphs 81-92 and 95.

Plant Uptake Tests

DECISIONS FROM PLANT UPTAKE/BIOASSAY TESTS

B61. Plant uptake/bioassay tests will indicate the potential for contaminants to impact plants colonizing the sediment to be dredged. Plant response is observed when index plants are grown in the sediment under both a flooded wetland condition and a dried upland condition as described in paragraph 61. Plant response is also observed in a reference sediment or soil selected according to paragraph 70. Both plant growth and bioaccumulation of contaminants are evaluated (Figure B6). Plant response to the contaminanted sediment should always be compared to the plant response to the reference sediment or soil. Data from existing literature on demonstrated effects of contaminants on plants (Tables C5 and C6) can be used to indicate potential effects of contaminant concentrations in test plants in relation to other plants and can give some perspective to the magnitude of the impact. Available FDA action levels for contaminants in plants and foodstuffs (Table C7) and existing standards for contaminant levels in food plants for protection of human health (Table C8) can be used to get additional perspective on contaminant concentrations in plant tissues that have potential health effects. Total plant uptake of contaminants should also be evaluated. Total uptake is calculated by multiplying the plant tissue concentration of contaminant by the total dry weight of plant leaves produced. Total uptake indicates the total

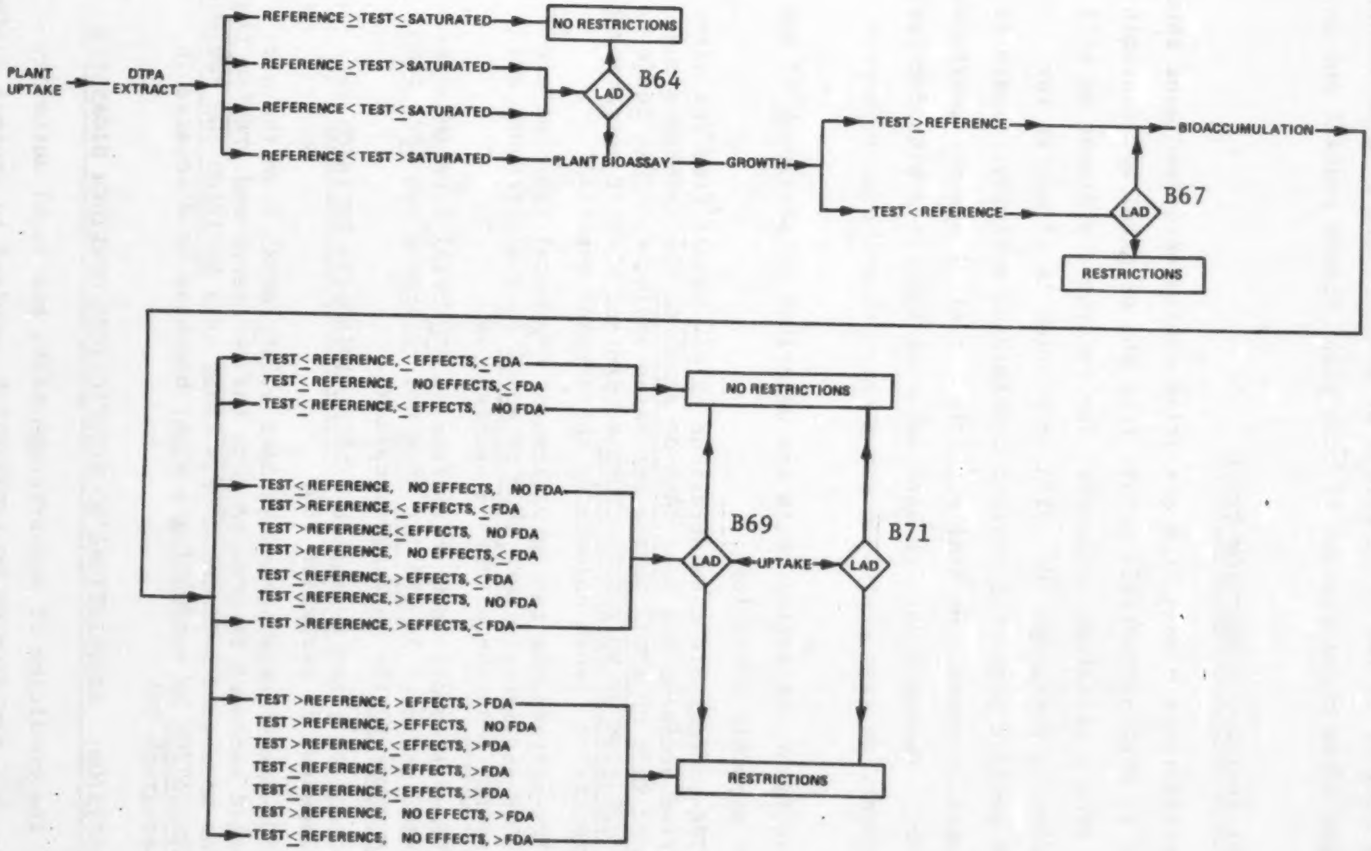
PLANT UPTAKE
DTPA EXTRACT
REFERENCE ≥ TEST ≤ SATURATED
REFERENCE ≥ TEST > SATURATED
REFERENCE < TEST ≤ SATURATED
REFERENCE < TEST > SATURATED
NO RESTRICTIONS
LAD
B64
PLANT BIOASSAY
GROWTH
TEST ≥ REFERENCE
TEST < REFERENCE
BIOACCUMULATION
LAD
B67
RESTRICTIONS
TEST ≤ REFERENCE, ≤ EFFECTS, ≤ FDA
TEST ≤ REFERENCE, NO EFFECTS, ≤ FDA
TEST ≤ REFERENCE, ≤ EFFECTS, NO FDA
NO RESTRICTIONS
TEST ≤ REFERENCE, NO EFFECTS, NO FDA
TEST > REFERENCE, ≤ EFFECTS, ≤ FDA
TEST > REFERENCE, ≤ EFFECTS, NO FDA
TEST > REFERENCE, NO EFFECTS, ≤ FDA
TEST ≤ REFERENCE, > EFFECTS, ≤ FDA
TEST ≤ REFERENCE, > EFFECTS, NO FDA
TEST > REFERENCE, > EFFECTS, ≤ FDA
LAD
B69
UPTAKE
LAD
B71
TEST > REFERENCE, > EFFECTS, > FDA
TEST > REFERENCE, > EFFECTS, NO FDA
TEST > REFERENCE, ≤ EFFECTS, > FDA
TEST ≤ REFERENCE, > EFFECTS, > FDA
TEST ≤ REFERENCE, ≤ EFFECTS, > FDA
TEST > REFERENCE, NO EFFECTS, > FDA
TEST ≤ REFERENCE, NO EFFECTS, > FDA
RESTRICTIONS

Figure B6. Flowchart for decisionmaking for potential plant uptake (number near LAD is paragraph discussing LAD)

mobility of contaminants from the sediment into aboveground portions of the plant. A complete picture of the plant uptake of contaminants from sediments can only be obtained after consideration of both plant tissue content and total uptake values.

DECISIONS FROM DTPA-SEDIMENT EXTRACTION TESTS

B62. DTPA-extractable metals from air-dried contaminated sediment should always be compared to DTPA-extractable metals from the original wet contaminated sediment and from a reference sediment. The reference sediment or soil is selected according to paragraph 70. DTPA extraction is effective for metals, but cannot predict potential organic contaminant mobility. There is no simplified laboratory extraction that predicts potential organic contaminant mobility into plants. Research data to date have not indicated bioaccumulation of organic comtaminants in test plants to any greater extent over reference plants.

B63. DTPA sediment extraction tests are described in paragraph 62 and can result in four possible conditions:

a. DTPA-extractable concentrations of *all* metals from the air-dried sediment are *less than or equal to* the reference and *less than or equal to* the saturated sediment. This leads to a DECISION OF NO RESTRICTIONS to protect against contaminant impacts on plants colonizing the dredged material.

b. DTPA-extractable concentrations of *any* metal from the air-dried sediment is *less than or equal to* the reference and *greater than* the saturated sediment or

c. DTPA-extractable concentrations of *any* metal from the air-dried sediment is *greater than* the reference and *less than or equal to* the saturated sediment.

Condition b and c lead to a LOCAL AUTHORITY DECISION as discussed in paragraph B64.

d. DTPA-extractable concentrations of *any* metal from the air-dried sediment is *greater than* the reference and *greater than* the saturated sediment. This leads to a DECISION FOR FURTHER EVALUATION by conducting a plant bioassay as discussed in paragraph B66.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER BIOASSAYS

B64. Under the condition of subparagraph B63b, the local authority might choose to reach a DECISION OF NO RESTRICTION required to protect against contaminant impacts on plants colonizing the contaminated dredged material. *This may be appropriate since plants will not be any more contaminated than* *those grown on the reference sediment even though contaminant mobility appears to have increased in the air-dried sediment compared to the saturated sediment. This may also be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the saturated sediment values by a small amount.* In the case of subparagraph B63c, the local authority might choose to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on plants colonizing the contaminated dredged material. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference sediment values by a small amount.* If the local authority desires to fully evaluate the potential for contaminant impacts on plants colonizing the contaminated dredged material to occur in light of the test results obtained in subparagraphs B63b and c, it will reach a DECISION FOR FURTHER EVALUATION by conducting a plant bioassay as discussed in paragraph B66.

B65. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B64 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B64 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. Number of contaminants. If 25 percent or less of the contaminants of concern are extracted from the air-dried dredged material in concentrations exceeding those from the air-dried reference sediment or the saturated dredged material, there is cause for *low concern*. If more than 25 percent of the contaminants of concern are extracted from the air-dried dredged material in concentrations exceeding those from the air-dried reference sediment or the saturated dredged material, there is cause for *high concern*.

b. **Magnitude above reference.** If air-dried dredged material produces DTPA-extracted metal concentrations of *10 or less times higher* than those from the air-dried reference sediment or the saturated dredged material, there is cause for *low concern*. If air-dried dredged material produces extract concentrations of *more than 10 times* the extract concentration from the air-dried reference sediment or the saturated dredged material, there is cause for *high concern*.

c. **Toxicological importance.** If the contaminants of concern extracted from air-dried dredged material in concentrations exceeding air-dried reference sediment concentrations or saturated dredged material concentrations are *rank 1-3* in Table C3, there is cause for *low concern*. If contaminants of concern extracted from air-dried dredged material are *unranked or ranked 4-6* in Table C3, there is cause for *high concern*.

d. **Number of sampling sites.** If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated produce DTPA-extracted metal concentrations from air-dried dredged material exceeding the air-dried reference sediment or the saturated dredged material, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites produce DTPA-extracted metal concentrations from air-dried dredged material exceeding the air-dried reference sediment or the saturated dredged material, there is cause for *high concern*.

Findings of *low concern in all factors* lead to a DECISION OF NO RESTRICTIONS required to protect from possible adverse impacts of dredged material disposed in the upland environment. A finding of *high concern* in *more than one of the factors* leads to a DECISION FOR FURTHER EVALUATION by conducting a plant bioassay as discussed in paragraph B66.

DECISIONS FROM PLANT BIOASSAY EVALUATIONS

B66. Plant bioassays as discussed in paragraphs 60 and 61 are evaluated in two phases, a growth phase evaluation and then a bioaccumulation phase (Figure B6). Plant growth can result in:

a. Air-dried sediment produces plant yield *equal to or greater than* that on the reference sediment. Up to 25 percent reduction in plant yield would be acceptable if the test sediment has poor fertility. This leads to a DECISION FOR FURTHER EVALUATION to assess potential bioaccumulation by conducting the bioaccumulation phase of the bioassay as discussed in paragraph B68.

b. Air-dried sediment produces a reduction in plant yield of *25 percent or greater* of that on the reference sediment. This leads to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: RESTRICTIONS/CONSIDER BIOACCUMULATION

B67. Under the conditions of subparagraph B66b, the local authority might choose to reach a DECISION FOR FURTHER EVALUATION by conducting the bioaccumulation phase of the plant bioassay. *This is appropriate if there is reason to believe the reduction in growth might be a result of low fertility in the sediment or a result of excess salt in the case of estuarine sediments.* On the other hand, the local authority might choose to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts on plants colonizing the dredged material. *This is appropriate if there is reason to believe that the reduction in growth was due to toxic metals or phytotoxic organic contaminants and not a result of infertility or salinity.* Some potentially appropriate restrictions are described in paragraphs 81-92 and 96.

DECISIONS FROM PLANT BIOACCUMULATION EVALUATIONS

B68. Plant bioaccumulation tests are described in paragraphs 60 and 61 and can give 17 possible sets of results grouped according to the appropriate decision to be made.

a. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and *less than or equal to* demonstrated effects (Tables C5 and C6) and *less than or equal to* FDA action levels (Table C7) or other human health effects levels (Table C8).

b. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues (but *no demonstrated effects data* exist) and are *less than or equal to* FDA action levels (Table C7) or other human health effects levels (Table A8).

c. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and *less than or equal to* demonstrated effects (Tables C5 and C6) but no FDA action levels or other human health effects levels exist.

Conditions a, b, and c lead to a DECISION OF NO RESTRICTIONS required to protect against contaminant impact on plants colonizing the dredged material.

d. Exposed plant tissue concentrations are *greater than* reference plant tissue and *greater than* demonstrated effects (Tables C5 and C6) and *greater than* FDA levels (Table C7) or other human health levels (Table C8).

e. Exposed plant tissue concentrations are *greater than* reference plant tissues and *greater than* demonstrated effects (Tables C5 and C6) and there are no FDA or other human health levels.

f. Exposed plant tissue concentrations are *greater than* reference plant tissues and *less than or equal to* demonstrated effects (Tables C5 and C6) and *greater than* FDA levels (Table C7) or other human health levels (Table C8).

g. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and *greater than* demonstrated effects (Tables C5 and C6) and *greater than* FDA levels (Table C7) or other human health levels (Table C8).

h. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and *less than or equal to* demonstrated effects (Tables C5 and C6) and *greater than* FDA levels (Table C7) or other human health levels (Table C8).

i. Exposed plant tissue concentrations are *greater than* reference plant tissues (but *no demonstrated effects data exist*) and are *greater than* FDA levels (Table C7) or other human health levels (Table C8).

j. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues (but *no demonstrated effects data exist*) and are *greater than* FDA levels (Table C7) or other human health levels (Table C8).

Conditions d-j lead to a DECISION FOR RESTRICTIONS required to protect against contaminant impact on plants colonizing the dredged material. Some potentially appropriate restrictions are described in paragraphs 81-92 and 96.

k. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and there are *no effects data* or *no FDA levels*.

l. Exposed plant tissue concentrations are *greater than* reference plant tissues and *less than or equal to* demonstrated effects (Tables C5 and C6) and *less than or equal to* FDA action levels (Table C7) or other human health effects levels (Table C8).

m. Exposed plant tissue concentrations are *greater than* reference plant tissues and *less than or equal to* demonstrated effects (Tables C5 and C6) and there are *no FDA or other human health levels*.

n. Exposed plant tissue concentrations are *greater than* reference plant tissues (but *no demonstrated effects data exist*), and are *less than or equal to* FDA levels (Table C7) or other human health levels (Table C8).

o. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues and *greater than* demonstrated effects (Tables C5 and C6) and *less than or equal to* FDA levels (Table C7) or other human health levels (Table C8).

p. Exposed plant tissue concentrations are *less than or equal to* reference plant tissues, and *greater than* demonstrated effects (Tables C5 and C6) but there are *no FDA* or other human health levels.

q. Exposed plant tissue concentrations are *greater than* reference plant tissues and *greater than* demonstrated effects (Tables C5 and C6) and *less than or equal to* FDA levels (Table C7) or other human health levels (Table C8).

Conditions k-q lead to a LOCAL AUTHORITY DECISION as discussed in paragraph B69.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER TOTAL PLANT UPTAKE

B69. At present it is not possible to provide sufficient scientific basis for deciding on the need for restrictions on the cases of subparagraphs B68k, l, m, n, o, p, and q. Therefore, the local authority must make an administrative decision using the available scientific information and locally important concerns. In interpreting plant bioaccumulation data, scientific concern over potential adverse impacts associated with bioaccumulation increases in direct relation to:

a. Number of contaminants bioaccumulated to concentrations exceeding reference and/or demonstrated effects levels.

b. Magnitude of bioaccumulation above reference and/or demonstrated effects levels.

c. Toxicological importance of contaminants bioaccumulated to concentrations exceeding reference and/or demonstrated effects levels. Contaminants that can be objectively ranked in this manner are presented in Table C3.

d. Proportion of sediment sampling sites in the area being evaluated that show bioaccumulation to concentrations exceeding reference and/or demonstrated effects levels.

In the cases of subparagraphs B68k, l, m, n, o, p, and q, the local authority may choose, without considering total plant uptake, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on plants colonizing the dredged material. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount.* On the other hand, the local authority may choose, without considering total plant uptake, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts on plants colonizing the dredged material. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 81-92 and 95. In addition, if the local authority desires to fully evaluate the potential for mass movement of contaminants into plants, it will reach a DECISION FOR FURTHER EVALUATION by considering total plant uptake as discussed in paragraph B71.

B70. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B69 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B69 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. Number of contaminants. If *25 percent or less* of the contaminants of concern (either metals or organics) are bioaccumulated to concentrations exceeding those in reference plants, there is cause for *low concern*. If *more than 25 percent* of the contaminants of concern (either metals or organics) exceed reference plants, there is cause for *high concern*.

b. Magnitude of tissue concentration. If dredged material produces tissue contaminant concentrations *within the normal range* and *below the critical content* shown in Table C5, there is cause for *low concern*. If dredged material produces tissue contaminant concentrations *greater than the normal range and equal to or greater than the critical content* shown in Table C5, there is cause for *high concern*.

c. Magnitude above reference. If dredged material produces tissue contaminant concentrations *10 or less times higher* than reference tissue concentrations, there is cause for *low concern*. If dredged material produces tissue concentrations *more than 10 times* the reference tissue concentration, there is cause for *high concern*.

d. Toxicological importance. If the contaminants of concern bioaccumulated to concentrations exceeding reference levels are *rank 1-3* in Table C3, there is cause for *low concern*. If the bioaccumulated contaminants are *ranked 4-6* in Table C3, there is cause for *high concern*. (Unranked contaminants of concern are cause for *moderate concern* unless there is additional evidence to reasonably warrant a different level of concern.)

e. **Number of sampling sites.** If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated produce bioaccumulation exceeding the reference sediment, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites produce bioaccumulation exceeding the reference sediment, there is cause for *high concern*. (If a single composite sample from the dredging area is tested, this factor drops from consideration.)

Findings of *low concern in all factors* lead to a DECISION OF NO RESTRICTIONS required to protect from possible adverse impacts of dredged material disposal in the upland environment. A finding of *moderate or high concern* in *one or more factors* leads to a DECISION OF RESTRICTIONS required to protect from possible adverse contaminant impacts of dredged material disposal in the upland environment. Some potentially appropriate restrictions of such cases are discussed in paragraphs 81-92 and 96.

DECISIONS FROM TOTAL PLANT UPTAKE EVALUATIONS

B71. Total plant uptake of contaminants can indicate potential mass movement of contaminants from the dredged material into plants. This is done by comparing the total uptake of contaminants (plant tissue concentration multiplied by total plant yield) from the contaminated sediment to that from the reference sediment:

a. If total uptake is *greater* on the contaminated sediment than that from the reference sediment, then the local authority may choose to reach a DECISION FOR RESTRICTIONS. *This may be appropriate in relation to the factors discussed in paragraph B70 if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference by a substantial margin.* On the other hand, the local authority might choose to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on plants colonizing the dredged material. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount.*

b. If total uptake is *less than or equal to* that from the reference sediment, then the local authority might reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on plants colonizing the dredged material. *This may be appropriate since contaminant mobility from the contaminated sediment into plants will not be any greater than existing contaminant mobility from the reference sediment into plants colonizing it.*

B72. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B71 using the following quantitative approach.*

This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B71 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.

a. Number of contaminants. If *25 percent or less* of the contaminants of concern show total uptake from the dredged material exceeding that from the reference sediment, there is cause for *low concern*. If *more than 25 percent* of the contaminants of concern show total uptake from the dredged material exceeding that from reference sediment, there is cause for *high concern*.

b. Magnitude above reference. If dredged material produces total uptake of contaminants of concern *10 or less times* higher than that from the reference sediment, there is cause for *low concern*. If dredged material produces total uptake of contaminants of concern *more than 10 times* that from the reference sediment, there is cause for *high concern*.

c. Toxicological importance. If the contaminants of concern showing total uptake from the dredged material exceeding reference levels are *rank 1-3* in Table C3, there is cause for *low concern*. If the contaminants of concern showing total uptake from the dredged material exceeding reference levels are *ranked 4-6* in Table C3, there is cause for *high concern*. (Unranked contaminants of concern are cause for *moderate concern* unless there is additional evidence to reasonably warrant a different level of concern.)

d. Number of sampling sites. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated produce total uptake values exceeding those of the reference sediment, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites produce total uptake values exceeding the reference sediment, there is cause for *high concern*. (If a single composite sample from the dredging area is tested, this factor drops from consideration.)

Findings of *low concern in all factors* lead to a DECISION OF NO RESTRICTIONS required to protect from adverse impacts of dredged material disposal in the upland environment. A finding of *moderate or high concern in one or more factors* leads to a DECISION OF RESTRICTIONS required to protect from possible adverse contaminant impacts of dredged material disposal in the upland environment. Some potentially appropriate restrictions of such cases are discussed in paragraphs 81-92 and 96.

Animal Uptake Tests

DECISIONS FROM ANIMAL UPTAKE/BIOASSAY TESTS

B73. Test animal response is observed after exposure to a contaminated sediment as described in paragraphs 63-65. Test animal response is also observed after exposure to a reference sediment or soil selected in accordance with paragraph 70. Both animal toxicity and bioaccumulation of contaminants are evaluated. Test animal response to contaminated sediment should always be compared to the response observed to the reference sediment or soil. Available FDA action levels for poisonous substances in human food (Table C1) can be used to get additional perspective on contaminant concentrations in organisms that have potential health effects. A direct correlation between earthworm content of contaminants and human health effects cannot be made. The earthworm bioassay only indicates the potential for contaminants to move from sediments into animals that come in contact with the sediment. Total animal uptake of contaminants should also be evaluated. Total uptake is calculated by multiplying the animal tissue concentration by the total dry weight of animal tissue produced. Total uptake indicates the total mobility of contaminants from the sediment into the test animal. A complete picture of the animal uptake of contaminants from sediments can only be obtained after consideration of both animal tissue content and total uptake values.

DECISIONS FROM ANIMAL TOXICITY EVALUATIONS

B74. Animal toxicity tests are described in paragraphs 63-65 and can result in four conditions (Figure B7):

a. Exposed toxicity is *greater than* the reference sediment and *equal to or greater than* 50 percentage points above the control. This leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts on sediment-dwelling animals beyond existing reference site conditions.

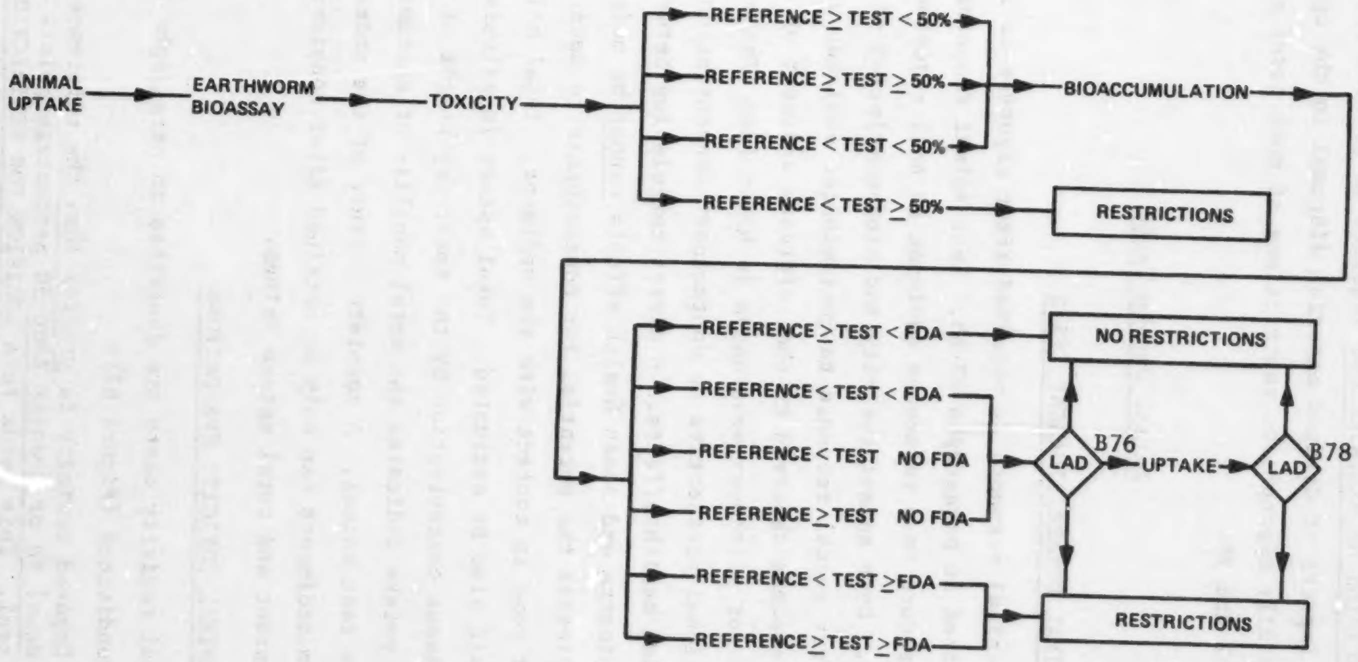
ANIMAL UPTAKE
EARTHWORM BIOASSAY
TOXICITY
REFERENCE ≥ TEST < 50%
REFERENCE ≥ TEST ≥ 50%
REFERENCE < TEST < 50%
REFERENCE < TEST ≥ 50%
BIOACCUMULATION
RESTRICTIONS
REFERENCE ≥ TEST < FDA
REFERENCE < TEST < FDA
REFERENCE < TEST NO FDA
REFERENCE ≥ TEST NO FDA
REFERENCE < TEST ≥ FDA
REFERENCE ≥ TEST ≥ FDA
NO RESTRICTIONS
LAD
B76
UPTAKE
LAD
B78
RESTRICTIONS

Figure B7. Flowchart for decisionmaking for potential animal uptake (number near LAD is paragraph discussing LAD)

b. Exposed toxicity is *less than or equal to* the reference sediment and *less than* 50 percentage points above the control.*

c. Exposed toxicity is *less than or equal to* the reference sediment and *equal to or greater than* 50 percentage points above the control, or

d. Exposed toxicity is greater than the reference sediment and *less than* 50 percentage points above the control.

Conditions under subparagraph B74b, c, and d lead to a DECISION FOR FURTHER EVALUATION by assessing the potential for bioaccumulation of contaminants of concern from the test sediment as discussed in paragraph B75.

DECISIONS FROM ANIMAL BIOACCUMULATION EVALUATIONS

B75. The local authority must evaluate the potential for bioaccumulation of contaminants from sediment/dredged material. Bioaccumulation tests can result in six conditions:

a. Concentrations of *all* contaminants of concern in the tissues of animals exposed to the test sediment are *less than or equal to* concentrations in animals exposed to the reference sediment and *less than* FDA type limits (Table C1). This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on soil-dwelling animals that colonize the dredged material.

b. Concentration of *any* contaminant of concern in the tissue of animals exposed to the test sediment are *greater than* reference animals and *equal to or greater than* FDA type limits (Table C1), or

c. Concentrations of *any* contaminant of concern in the tissues of exposed animals are *less than or equal to* reference animals and *equal to or greater than* FDA-type limits (Table C1).

Conditions under subparagraphs B75b and c lead to a DECISION FOR RESTRICTIONS required to protect against possible contaminant impacts on soil dwelling animals that colonize the disposal site. Some potentially appropriate restrictions are described in paragraphs 81-92 and 96.

d. Concentrations of *any* contaminant of concern in the tissues of animals exposed to the test sediment are *greater than* reference animals and *less than* FDA-type limits (Table C1), or

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* For example, if 9 of 100 control animals showed mortality, then at least 59 of 100 test animals (59 percent) would have to show mortality in order for toxicity of the test sediment to be 50 percentage points above the control.

e. Concentrations of *any* contaminant of concern in the tissues of animals exposed to the test sediment are *greater than* reference animals and *no FDA-type limits have been established* (Table C1), or

f. Concentrations of *any* contaminant of concern in the tissues of animals exposed to the test sediment are *less than or equal to* reference animals and *no FDA-type limits have been established* (Table C1).

Conditions under subparagraphs B75d, e, and f lead to a LOCAL AUTHORITY DECISION.

LOCAL AUTHORITY DECISION: RESTRICTIONS/NO RESTRICTIONS/CONSIDER TOTAL ANIMAL UPTAKE

B76. At present it is not possible to provide sufficient scientific basis for deciding on the need for restrictions on the cases of subparagraphs B75d, e, and f. Therefore, the local authority must make an administrative decision using the available scientific information and locally important concerns. In interpreting animal bioaccumulation data, scientific concern over potential adverse impacts associated with bioaccumulation increases in direct relation to:

a. Number of contaminants bioaccumulated to concentrations exceeding reference and/or demonstrated effects levels.

b. Magnitude of bioaccumulation above reference and/or demonstrated effects levels.

c. Toxicological importance of contaminants bioaccumulated to concentrations exceeding reference and/or demonstrated effects levels. Contaminants that can be objectively ranked in this manner are presented in Table C3.

d. Proportion of sediment sampling sites in the area being evaluated that show bioaccumulation to concentrations exceeding reference and/or demonstrated effects levels.

In the cases of subparagraphs B75d, e, and f, the local authority may choose, without considering total animal uptake, to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on soil-dwelling animals colonizing the dredged material. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount.* On the other hand, the local authority may choose, without considering total animal uptake, to reach a DECISION FOR RESTRICTIONS required to protect against contaminant impacts on soil-dwelling animals colonizing the dredged material. *This may be appropriate if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference by a substantial margin.* Some potentially appropriate restrictions are described in paragraphs 81-92 and and 96. In addition, if the local authority desires to fully evaluate the potential mass movement of contaminants into soil-dwelling animals, it will reach a DECISION FOR FURTHER EVALUATION by considering total animal uptake as discussed in paragraph B78.

B77. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B76 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B76 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. Number of contaminants. If *25 percent or less* of the contaminants of concern are bioaccumulated to concentrations exceeding those in reference animals, there is cause for *low concern*. If *more than 25 percent* of the contaminants of concern exceed reference animals, there is cause for *high concern*.

b. Magnitude above reference. If dredged material produces tissue contaminant concentrations *10 or less times* higher than reference tissue concentrations, there is cause for *low concern*. If dredged material produces tissue concentrations *more than 10 times* the reference tissue concentration, there is cause for *high concern*.

c. Toxicological importance. If the contaminants of concern bioaccumulated to concentrations exceeding reference levels are *rank 1-3* in Table C3, there is cause for *low concern*. If the bioaccumulated contaminants are *ranked 4-6* in Table C3, there is cause for *high concern*. (Unranked contaminants of concern are cause for *moderate concern* unless there is additional evidence to reasonably warrant a different level of concern.)

d. Number of sampling sites. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated produce bioaccumulation exceeding the reference sediment, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites produce bioaccumulation exceeding the reference sediment, there is cause for *high concern*. (If a single composite sample from the dredging area is tested, this factor drops from consideration.)

Findings of *low concern in all factors* lead to a DECISION OF NO RESTRICTIONS required to protect from possible adverse impacts of dredged material disposal in the upland environment. A finding of *moderate or high concern in one or more factors* leads to a DECISION OF RESTRICTIONS required to protect from possible adverse contaminant impacts of dredged material disposal in the upland environment. Some potentially appropriate restrictions of such cases are discussed in paragraphs 81-92 and 96.

DECISIONS FROM TOTAL ANIMAL UPTAKE EVALUATIONS

B78. Total animal uptake of contaminants can indicate potential mass movement of contaminants from the dredged material into soil-dwelling animals. This is done by comparing the total uptake of contaminants (animal tissue concentration multiplied by total animal weight) from the contaminated sediment to that from the reference sediment:

a. If total uptake is *greater* on the contaminated sediment than that from the reference sediment, then the local authority may choose to reach a DECISION FOR RESTRICTIONS. *This may be appropriate in relation to the factors discussed in paragraph B76 if samples from a number of sites have several contaminants of relatively high toxicological concern exceeding the reference by a substantial margin.* On the other hand, the local authority might choose to reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on animals colonizing the dredged material. *This may be appropriate if samples from only a few sites have only a small number of contaminants of relatively low toxicological concern exceeding the reference by a small amount.*

b. If total uptake is *less than or equal to* that from the reference sediment, than the local authority might reach a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts on animals colonizing the dredged material. *This may be appropriate since contaminant mobility from the contaminated sediment into soil-dwelling animals will not be any greater than existing contaminant mobility from the reference sediment into animals colonizing it.*

B79. *Commencement Bay area authorities have tentatively decided to make the LAD discussed in paragraph B78 using the following quantitative approach. This quantitation was selected for use when Commencement Bay area goals (paragraph 70) require the use of a relatively pristine reference, as is the case in the example in Part III and Tables 3-21. Other values may be necessary to achieve local goals that utilize a less pristine reference. Although conceptually similar approaches could be taken elsewhere, the approach and its quantitation would have to be tailored specifically to local goals. The authors do not necessarily advocate either quantitation of the guidance of paragraph B78 or its quantitation in the following manner since the guidance considerations may be complexly interactive. The approach described below is the initial approach tentatively selected by Commencement Bay area authorities and should not be construed as final Commencement Bay area guidance nor as implied guidance or a precedent for actual LADs elsewhere.*

a. Number of contaminants. If *25 percent or less* of the contaminants of concern show total uptake from the test sediment exceeding that from the reference sediment, there is cause for *low concern*. If *more than 25 percent* of the contaminants of concern show total uptake from the test sediment exceeding that from the reference sediment, there is cause for *high concern*.

b. Magnitude above reference. If dredged material produces total uptake of contaminants of concern *10 or less times higher* than that from the reference sediment, there is cause for *low concern*. If dredged material produces total uptake *more than 10 times* that from the reference sediment, there is cause for *high concern*.

c. Toxicological importance. If the contaminants of concern showing total uptake exceeding reference levels are *rank 1-3* in Table C3, there is cause for *low concern*. If the bioaccumulated contaminants are *ranked 4-6* in Table C3, there is cause for *high concern*. (Unranked contaminants of concern are cause for *moderate concern* unless there is additional evidence to reasonably warrant a different level of concern.)

d. Number of sampling sites. If *50 percent or less* of the sediment sampling sites in the dredging area being evaluated produce bioaccumulation exceeding the reference sediment, there is cause for *low concern*. If *more than 50 percent* of the sediment sampling sites produce bioaccumulation exceeding the reference sediment, there is cause for *high concern*. (If a single composite sample from the dredging area is tested, this factor drops from consideration.)

Findings of *low concern in all factors* lead to a DECISION OF NO RESTRICTIONS required to protect from possible adverse impacts of dredged material disposal in the upland environment. A finding of _moderate or high concern in one or more factors_ leads to a DECISION OF RESTRICTIONS required to protect from possible adverse contaminant impacts of dredged material disposal in the upland environment. Some potentially appropriate restrictions of such cases are discussed in paragraphs 81-92 and 96.

Human Exposure Evaluation

B80. There are recommended limitations on the amount of sewage sludge metals that can be applied to agricultural crop land as related to background metal levels (Tables C9 and C10). Based on these limitations, a potential for human exposure of contaminants of concern in the test sediment under upland disposal environments could be evaluated by comparing total bulk chemical analysis data for the test sediment/dredged material to the values for soil ingestion in Table C10. Soil ingestion could result from breathing dust and/or actual contact and intake of soil such as is the case with a child playing on the ground. In England surface soil contaminant limitations for human exposure are based on a child eating a handful of soil while playing on the ground. While this approach to human exposure assessment may be crude and oversimplified, it can give some perspective to the potential human exposure that is evaluated for agricultural cropland and in Europe. This evaluation for human exposure could be used as guidance to the LAD for allowing the public access to the disposal site. In addition, the LAD might be to limit agricultural production of edible crops on test sediment/dredged material containing metal concentrations in excess of that allowed for sewage sludge application (Table C9). Two conditions can result (Figure B8):

a. Concentrations of contaminants of concern in the test sediment/dredged material are _less than or equal to_ those specified in Tables C9 and C10. This leads to a DECISION OF NO RESTRICTIONS required to protect against contaminant impacts due to human exposure to the test sediment/dredged material.

b. Concentrations of _any_ contaminants of concern in the test sediment/dredged material is _greater than_ that specified in Tables C9 and C10. This leads to a DECISION FOR RESTRICTIONS required to protect against contaminant impacts due to human exposure to the test sediment/dredged material. Some potentially appropriate restrictions are described in paragraphs 81-92 and 96.

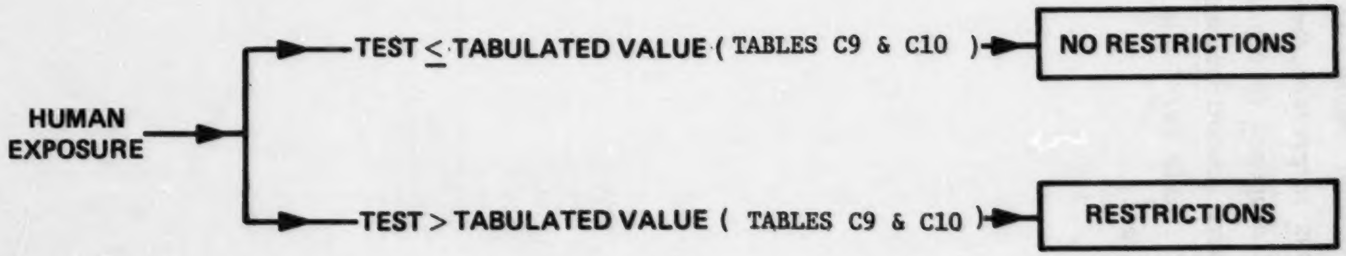
HUMAN EXPOSURE
TEST ≤ TABULATED VALUE (TABLES C9 & C10)
NO RESTRICTIONS
TEST > TABULATED VALUE (TABLES C9 & C10)
RESTRICTIONS

Figure B8. Flowchart for decisionmaking for potential human exposure

B81. *Commencement Bay area authorities have tentatively decided to make the LAD that dredged material containing contaminant concentrations in the range of background levels for US cropland (Table C9) leads to a* DECISION FOR NO FURTHER TESTING *and* NO RESTRICTIONS *to protect from possible adverse contaminant impacts of dredged material disposal in the upland environment. Dredged material containing contaminant concentrations greater than the range of background levels for US cropland (Table C9) leads to a* DECISION FOR FURTHER EVALUATION *by conducting additional tests.*

APPENDIX C: RELATED INFORMATION AND DATA TABLES

Table Number	Topic
C1	Action Levels for Contaminants in Aquatic Organisms for Human Consumption
C2	US Environmental Protection Agency (EPA) Water Quality Criteria for the Protection of Aquatic Life
C3	Ranking of Toxicological Importance of Contaminants Based on EPA 24-hr Average (Chronic) Water Quality Criteria for the Protection of Fresh Water or Saltwater Aquatic Life
C4	Contaminant Concentrations in Drinking Water Standards
C5	Demonstrated Effects of Contaminants on Plants
C6	Maximum Recommended Application of Municipal Sludge-Applied Metals to Medium-Textured Cropland Soils to Prevent Phytotoxicity
C7	Action Levels for Various Heavy Metals and Pesticides in Plants and Foodstuffs
C8	Additional Action Levels for Contaminants in Foodstuffs Used by Other Countries
C9	Background Levels and Allowable Applications of Several Heavy Metals for US Cropland Soils
C10	Recommended or Regulated Limitations on Potentially Toxic Constituents in Surface Soils

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NOTE: All references cited in this appendix are included in the list of references that follows the main text.

Table C1

Action Levels for Contaminants in Aquatic Organisms for Human Consumption

Chemical	Food	Action Level* (mg/kg wet weight edible portions)	Maximum Concentration** (mg/kg wet weight edible portions)
Aldrin	Fish and shellfish	0.3	
Antimony	All nonspecified foods (including seafood)		1.5
Arsenic	Fish, crustacea, molluscs		1.0
Cadmium	Fish		0.2
	Molluscs		1.0
Chlordane	Fish	0.3	
Copper	Molluscs		70.0
	All nonspecified foods (including seafood)		10.0
DDT, DDE, TDE	Fish	5.0†	
Dieldrin	Fish and shellfish	0.3	
Endrin	Fish and shellfish	0.3	
Heptachlor, heptachlor epoxide	Fish and shellfish	0.3†	
Hexachlorocyclohexane (Benzene hexachloride)	Frog legs		0.5
Kepone	Fish and shellfish	0.3	
	Crabmeat	0.4	
Lead	Molluscs		2.5
	All nonspecified foods (including seafood)		1.5

(Continued)

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* United States Food and Drug Administration (FDA) Action Levels for Poisonous or Deleterious Substances in Human Food.

** Australian National Health and Medical Research Council Standards for Metals in Food, May 1980.

† Action level is for these chemicals individually or in combination. However, in adding concentrations, do not count any concentrations below the following levels:

Chemical	Minimum level (mg/kg)
DDT, DDE, TDE	0.2
Heptachlor, heptachlor epoxide	0.3

Table C1 (Concluded)

Chemical	Food	Action Level (mg/kg wet weight edible portions)	Maximum Concentration (mg/kg wet weight edible portions)
Mercury	Fish, crustacea, molluscs		0.5
Methylmercury	Fish, shellfish, other aquatic animals	1.0	
Mirex	Fish	0.1	
PCB (total)	Fish and shellfish	2.0††	
Selenium	All nonspecified foods (including seafood)		1.0
Tin	Fish		50.0
Toxaphene	Fish	5.0	
Zinc	Oysters		1,000.0
	All nonspecified foods (including seafood)		150

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†† This is not an action level but a tolerance limit established through the rulemaking process.

Table C2

US Environmental Protection Agency (EPA) Water Quality Criteria for the Protection of Aquatic Life. Federal Register, Vol 45, No. 231, Friday, November 28, 1980, pp 79318-79357

Chemical	Criterion for Protection of Aquatic Life, µg/ℓ: Saltwater: 24-hr avg (chronic)	Saltwater: Maximum at any time (acute)	Fresh Water: 24-hr avg (chronic)	Fresh Water: Maximum at any time (acute)
Aldrin	--	1.3	--	3.0
Arsenic (total trivalent)	--	--	--	440
Cadmium[1]	4.5	59		
50 mg/ℓ $CaCO_3$			0.012	1.5
100 mg/ℓ $CaCO_3$			0.025	3.0
200 mg/ℓ $CaCO_3$			0.051	6.3
Chlordane	0.0040	0.09	0.0043	2.4
Chromium (total trivalent)[2]	--	--		
50 mg/ℓ $CaCO_3$			--	2,200
100 mg/ℓ $CaCO_3$			--	4,700
200 mg/ℓ $CaCO_3$			--	9,900
Chromium (total hexavelent)	18	1,260	0.29	21
Copper[3]	4.0	23	5.6	
50 mg/ℓ $CaCO_3$				12
100 mg/ℓ $CaCO_3$				22
200 mg/ℓ $CaCO_3$				43
Cyanide (free)	--	--	3.5	52
Dieldrin	0.0019	0.71	0.0019	2.5
DDT	0.0010	0.13	0.0010	1.1
TDE	--	--	--	--
DDE	--	--	--	--
Endosulfan	0.0087	0.034	0.056	0.22
Endrin	0.0023	0.037	0.0023	0.18
Heptachlor	0.0036	0.053	0.0038	0.52

(Continued)

Table C2 (Concluded)

Chemical	Criterion for Protection of Aquatic Life, µg/ℓ: Saltwater 24-hr avg (chronic)	Saltwater Maximum at any time (acute)	Fresh Water 24-hr avg (chronic)	Fresh Water Maximum at any time (acute)
Lindane	--	0.16	0.080	2.0
Lead[4]	--	--		
50 mg/ℓ $CaCO_3$			0.75	74
100 mg/ℓ $CaCO_3$			3.8	170
200 mg/ℓ $CaCO_3$			20	400
Mercury	0.025	3.7	0.00057	0.0017
Nickel[5]	7.1	140		
50 mg/ℓ $CaCO_3$			56	1,100
100 mg/ℓ $CaCO_3$			96	1,800
200 mg/ℓ $CaCO_3$			160	3,100
PCB (total)	0.030	0.030	0.014	0.014
Selenium				
inorganic selenite	54	410	35	260
Silver[6]	--	2.3		
50 mg/ℓ $CaCO_3$			--	1.2
100 mg/ℓ $CaCO_3$			--	4.1
200 mg/ℓ $CaCO_3$			--	13
Toxaphene	--	0.070	0.013	1.6
Zinc[7]	58	170	47	
50 mg/ℓ $CaCO_3$				180
100 mg/ℓ $CaCO_3$				320
200 mg/ℓ $CaCO_3$				570

Note: Criteria for some metals in fresh water are hardness-dependent and are derived from the following equations, where h is hardness in mg/ℓ as $CaCO_3$, and e is the natural logrithm base.

Metal	24-hr avg	Maximum at any time
[1] Cadmium	$e^{1.05 (\ln h) - 8.53}$	$e^{1.05 (\ln h) - 3.73}$
[2] Chromium (total trivalent)	---	$e^{1.08 (\ln h) + 3.48}$
[3] Copper	(main table)	$e^{0.94 (\ln h) - 1.23}$
[4] Lead	$e^{2.35 (\ln h) - 9.48}$	$e^{1.22 (\ln h) - 0.47}$
[5] Nickel	$e^{0.76 (\ln h) + 1.06}$	$e^{0.76 (\ln h) + 4.02}$
[6] Silver	--	$e^{1.72 (\ln h) - 6.52}$
[7] Zinc	$e^{0.83 (\ln h) + 1.95}$	(main table)

-- indicates criterion not established

Table C3

Ranking of Toxicological Importance of Contaminants Based on EPA 24-hr Average (Chronic) Water Quality Criteria for the Protection of Fresh Water or Saltwater Aquatic Life

Fresh Water			Saltwater		
Rank	Criterion Range μg/ℓ*	Contaminant**	Rank	Criterion Range μg/ℓ	Contaminant**
6	0.0001-0.001	Mercury	6	0.0001-0.001	†
5	0.001-0.01	DDT Dieldrin Endrin Heptachlor Chlordane	5	0.001-0.01	DDT Dieldrin Endrin Heptachlor Chlordane Endosulfan
4	0.01-0.1	Toxaphene PCB (total) Cadmium Endosulfan Lindane	4	0.01-0.1	Mercury PCB (total)
3	0.1-1.0	Chromium	3	0.1-1.0	†
2	1-10	Cyanide Lead Copper	2	1-10	Copper Cadmium Nickel
1	10-100	Selenium Zinc Nickel	1	10-100	Selenium Zinc

---

* For fresh water, metals are ranked according to the criterion at a hardness of 100 mg/ℓ $CaCO_3$.

** Within each rank, contaminants are listed in order of increasing criterion values.

† No saltwater chronic criteria fall in this range.

Table C4

Contaminant Concentrations in Drinking Water Standards

Parameter, mg/ℓ unless otherwise noted	Drinking Water Standards Federal	State of Washington
Arsenic	0.05	0.05
Barium	1.0	1.0
Cadmium	0.010	0.010
Chromium	0.05	0.05
Lead	0.05	0.05
Mercury	0.002	0.002
Selenium	0.01	0.01
Silver	0.05	0.05
Fluoride	1.4-2.4	1.4-2.4
Nitrate (as N)	10.0	10.0
Endrin	0.0002	0.0002
Lindane	0.004	0.004
Methoxychlor	0.1	0.1
Toxaphene	0.005	0.005
2,4-D	0.1	0.1
2,4,5-TP Silvex	0.01	0.01
Trihalomethanes	0.1	0.1
Turbidity (JU)	1.0	1.0
Coliform bacteria -membrane filter test (#/100 mℓ)	1.0	1.0
Gross alpha (pCi/ℓ)	15.0	15.0
Combined Radium 226 and Radium 228	5.0	5.0
Beta and photon particle activity (Mrem/yr)	4.0	4.0
Sodium	Monitor	250.0
Chloride	250.0	250.0
Color (units)	15.0	15.0
Copper	1.0	1.0
Corrosivity	Noncorrosive	Noncorrosive
Foaming agents	0.5	0.5
Iron	0.3	0.3
Manganese	0.05	0.05
Odor (threshold No.)	3.0	3.0
pH (units)	6.5-8.5	6.5-8.5
Sulfate	250.0	250.0
Total dissolved solids	500.0	500.0
Zinc	5.0	5.0

Table C5

Demonstrated Effects of Contaminants on Plants

		Plant Growth			
Contaminant	Normal*	"Critical" Content** mg/kg leaves	10%** Yield Reduction mg/kg leaves	25%† Yield Reduction mg/kg leaves	Phytotoxic*
As	0.1-1	--	--	--	3-10
B	775	--	--	--	75
Cd	0.1-1	8	15	Varies	5-700
Co	0.01-0.3	--	--	--	25-100
Cr^{+3}, Oxides	0.1-1	--	--	--	20
Cu	3-20	20	20	20-40	25-40
F	1-5	--	--	--	--
Fe	30-300	--	--	--	--
Mn	15-150	--	--	500	400-2,000
Mo	0.1-3.0	--	--	--	100
Ni	0.1-5	11	26	50-100	500-1,000
Pb	2-5	--	--	--	--
Se	0.1-2	--	--	--	100
V	0.1-1	--	--	--	10
Zn	15-150	200	290	500	500-1,500

---

* From Chaney, R. L. (1983).

** From Davis, Beckett, and Wollan (1978), Davis and Beckett (1978), Beckett and Davis (1977).

† From Chaney et al. (1978).

Table C6

Maximum Recommended Application of Municipal Sludge-Applied Metals to Medium-Textured Cropland Soils to Prevent Phytotoxicity*

Contaminant	Maximum Application		
	kg/ha	lb/a	mg/kg
Pb	1,000	891	500**
Zn	560	446	250
Cu	280	223	125
Ni	112	111	62
Cd	11.2	4.5	2.5

Note: Soil bulk density 1.33; potentially acidic soil. Recommended limits to prevent yield reduction in sensitive vegetable crops at pH ≥ 6.2 , or most crops and cover crops at pH ≥ 5.5 .

* USEPA, USDA, USFDA (1980).

** Maximum allowable Pb content in soil for human child exposure as related to direct soil ingestion in the United Kingdom and in the United States.

Table C7

Action Levels for Various Heavy Metals and Pesticides in Plants and Foodstuffs

Substance	Commodity	Data Source*	Action Level	Type of Limit**	Step†	Reference††
Aflatoxin	Feeds	1	20.0 ppb	--	--	CPA 7126.33
	Brazil Nuts	1	20.0 mcgs/kg	--	--	CPG 7112.07
	Peanuts	1	20.0 mcgs/kg	--	--	CPG 7112.02
	Pistachio nuts	1	20.0 mcgs/kg	--	--	CPG 7112.08
Aldrin and Dieldrin	Grain (raw cereal)	2	0.02 mg/kg	PRL	9	--
	Rice (in the husk)	2	0.02 mg/kg	T	9	--
	Animal feed	1	0.03 ppm	--	--	CPG 7126.27-A
	Vegetables	2	0.1 mg/kg	T	9	--
	Artichokes	1	0.05 ppm	--	--	CPG 7120.23-A
	Lettuce and carrots	2	0.1 mg/kg	PRL	9	--
	Fruits	1	0.05 ppm	--	--	CPG 7120.23-A
	Melons	1	0.15 ppm	--	--	CPG 7120.23-A
	Sugarbeet pulp	1	0.1 ppm	--	--	CPG 7126.27-A
Arsenic	Non-pulpy black-current nectar	3	0.2 mg/kg	--	--	CAC/RS 101-1978
	Fructose	3	1 mg/kg			CAC/RS 102-1978
	Cocoa powders and dry cocoa-sugar mixtures	3	1 mg/kg			CAC/RS 105-1978
Benzene Hexachloride (BHC)	Grain (animal feed)	1	0.1 ppm	--	--	CPG 7126.27-B
	Grain (human food)	1	0.1 ppm	--	--	CPG 7120.23-B
	Vegetables	1	0.5 ppm	--	--	CPG 7120.23-B
	Fruits	1	0.5 ppm	--	--	CPG 7120.23-B
Cadmium	Provisional weekly tolerance intake for humans	2	0.0067-0.0083 mg/kg body weight			

(Continued)

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* Data source:
  1 = FDA action levels for poisonous or deleterious substances in human food and animal feed,
  2 = FAO/WHO guide to Codex Maximum Limits for Pesticide Residues,
  3 = List of maximum levels recommended for contaminants by the joint FAO/WHO Codex Alimentarius Commission. Joint FAO/WHO food standards programme Codex Alimentarius Commission CAC/FAL 4-1978.

** Type of limit:
  CPG = Compliance Policy Guidelines,
  TT = Temporary Codex Tolerance,
  T = Codex Tolerance, and
  PRL = Practical Residue Limit.

† Step = "Step" in the procedure for the elaboration of Codex Maximum Limits for Pesticide Residue given in the FAO/WHO Gude to CODEX M.

†† Reference = Refers to CPG number.

(Sheet 1 of 5)

Table C7 (Continued)

Substance	Commodity	Data Source	Action Level	Type of Limit	Step	Reference
Chlordane	Root and tuber vegetables	2	0.3 mg/kg	T	6	71(1)
	Sugar beet	2	0.3 mg/kg	T	9	—
	Leafy vegetables	2	0.2 mg/kg	T	6	71(1)
	Stem vegetables	2	0.2 mg/kg	T	6	71(1)
	Legume vegetables	2	0.02 mg/kg	T	9	—
	Fruiting vegetables	2	0.1 mg/kg	T	9	—
	Citrus fruits	2	0.02 mg/kg	T	9	—
	Assorted fruits	2	0.1 mg/kg	T	9	—
	Pineapple	2	0.1 mg/kg	T	6	—
	Passion fruit	2	0.1 mg/kg	T	9	—
	Pome fruit	2	0.1 mg/kg	T	6	72(1)
	Stone fruit	2	0.02 mg/kg	T	9	—
	Small fruits and berries	2	0.02 mg/kg	T	9	—
	Cottonseed oil, crude	2	0.1 mg/kg	T	6	—
	Cottonseed oil, edible	2	0.1 mg/kg	T	9	—
	Linseed oil, crude	2	0.02 mg/kg	T	9	—
	Soya bean oil, crude	2	0.5 mg/kg	T	9	—
	Soya bean oil, edible	2	0.5 mg/kg	T	9	—
	Grain, animal feed	2	0.02 mg/kg	T	9	—
	Nuts	1	0.1 ppm	—	—	CPG 7126.27-C
		2	0.1 mg/kg	—	—	—
Copper	Non-pulpy black-current nectar	3	5 mg/kg	—	—	CAC/RS 101-1978
	Fructose	3	2 mg/kg	—	—	CAC/RS 102-1978
	Cocoa powders and dry cocoa-sugar mixtures	3	50 mg/kg	—	—	CAC/RS 105-1978
	Edible acid casein	3	5 mg/kg	—	—	18th sessions-1976
	Edible caseinates	3	5 mg/kg	—	—	App. VI, CS 5/70 18th session-1976
Crotalaria Seeds	Grains and feeds	1	Avg of one whole seed/pound	—	—	CPG 7126.15
Dibromochloropropane (DBCP)	Raw agricultural commodities	1	0.05 ppm	—	—	CPG-7120.23-E
DDT, DDE, and TDE	Grain, animal feed	1	0.5 ppm	—	—	CPG 7126.27-D
	Grain, human food	1	0.5 ppm	—	—	CPG 7120.23-D
	Cocoa beans	1	2.0 ppm	—	—	CPG 7120.23-D
Endrin	Vegetables	1	0.05 ppm	—	—	CPG 7120.23-E
	Fruits	1	0.05 ppm	—	—	CPG 7120.23-E
	Oilseed meal, animal feed	1	0.03 ppm	—	—	CPG 7126.27-E
	Cottonseed oil, crude	2	0.1 mg/kg	T	9	—
	Cottonseed oil, edible	2	0.02 mg/kg	T	9	—
	Linseed oil, crude	2	0.5 mg/kg	T	9	—

(Continued)

(Sheet 2 of 5)

Table C7 (Continued)

Substance	Commodity	Data Source	Action Level	Type of Limit	Step	Reference
Endrin (Continued)	Soya bean oil, crude	2	0.5 mg/kg	T	9	--
	Soya bean oil, edible	2	0.02 mg/kg	T	9	--
	Vegetable oils and fats	1	0.3 ppm	--	--	CPG-7126.27-E
	Nuts	2	0.1 mg/kg	T	6	72 (1)
Fenthion	Root and tuber vegetables	2	0.1 mg/kg	TT	3	JMPR 1977
	Bulb vegetables	2	0.1 mg/kg	TT	3	JMPR 1977
	Squash	2	0.2 mg/kg	TT	6	--
	Ground red peppers	1	0.3 ppm	--	--	CPG 7120.23-G
	Leafy vegetables	2	2.0 mg/kg	TT	6	--
	Brassica leafy vegetables	2	1.0 mg/kg	TT	6	--
	Legume vegetables	2	0.1 mg/kg	TT	3	--
	Assorted fruits	2	2.0 mg/kg	TT	6	--
	Bananas	2	1.0 mg/kg	TT	3	JMPR 1977
	Stone fruits	2	0.2 mg/kg	TT	6	--
	Plums	2	0.1 mg/kg	TT	3	JMPR 1977
	Small fruits and berries	2	0.2 mg/kg	TT	3	JMPR 1977
	Grapes	2	0.5 mg/kg	TT	6	--
	Cereal grains	2	0.1 mg/kg	TT	6	--
	Oilseed	2	0.1 mg/kg	TT	6	--
Heptachlor	Vegetables	2	0.05 mg/kg	PRL	9	--
	Vegetables	1	0.05 ppm	--	--	7120.23-H
	Tomato	2	0.02 mg/kg	PRL	9	--
	Carrot	2	0.2 mg/kg	PRL	9	--
	Sugar beet	2	0.05 mg/kg	PRL	9	--
	Fruits	1	0.05 ppm	--	--	CPG 7120.23-H
	Fruits	2	0.01 mg/kg	PRL	9	--
	Grain, animal feed	1	0.03 ppm	--	--	CPG 7126.27-F
	Grain, human food	1	0.03 ppm	--	--	CPG 7120.23-H
	Raw cereal	2	0.02 mg/kg	PRL	9	--
	Soya bean oil, crude	2	0.5 mg/kg	PRL	9	--
	Soya bean oil, edible	2	0.02 mg/kg	PRL	9	--
	Cottonseed	2	0.02 mg/kg	PRL	9	--
Iron	Non-pulpy black currant nectar	3	15 mg/kg	--	--	CAC/RS 101-1978, App. V., CX 5/70
	Edible acid casein	3	20 mg/kg	--	--	18th session-1976
	Edible caseinates	3	50 mg/kg	--	--	App. VI, CX 5/70 18th session-1976
Kelthane	Animal feed	1	0.5 ppm	--	--	CPG 7126.27G
Kepone	--	--	--	--	--	--

(Continued)

(Sheet 3 of 5)

Table C7 (Continued)

Substance	Commodity	Data Source	Action Level	Type of Limit	Step	Reference
Lead	Non-pulpy black currant nectar	3	0.3 mg/kg	—	—	CAC/RS 101-1978
	Cocoa powders and dry cocoa-sugar mixtures	3	2 mg/kg	—	—	CAC/RS 105-1978
	Edible acid casein	3	2	—	—	App. V, CS 5/70 18th session
	Edible caseinates	3	2	—	—	App. VI, CS 5/70 18th session
Lindane	Vegetables	1	0.5 ppm	—	—	CPG 7120.23-J
	Root and tuber vegetables	2	0.05 mg/kg	T	5	JMPR 1975
	Leafy vegetables	2	0.2 mg/kg	T	3	JMPR 1975
	Brassica vegetables	2	0.5 mg/kg	T	3	JMPR 1975
	Stem vegetables	2	0.5 mg/kg	T	5	JMPR 1975
	Legume vegetables	2	0.1 mg/kg	T	9	109 (1)
	Peas	2	0.1 mg/kg	T	5	JMPR 1975
	Assorted fruits	2	0.5 mg/kg	T	9	110 (1)
	Small fruits and berries	2	0.5 mg/kg	T	3	111 (5)
	Cranberries	2	0.3 mg/kg	T	5	
	Fruits	1	0.5 ppm	—	—	CPG 7120.23-J
	Grain, animal feed	1	0.1 ppm	—	—	CPG 7126.27-H
	Grain, human food	1	0.1 ppm	—	—	CPG 7120.23-J
Mercury	Wheat (pink kernals only)	1	1.0 ppm	—	—	CPG 7104.05
	Provisional tolerable weekly intake for humans	3	0.005 mg total Hg/kg body weight 0.0033 mg methylmercury/kg body weight			
Methyl alcohol	Imported brandy	1	0.35 percent	—	—	CPG 7119.09
Nitrosodimethylamine (NDMA)	Barley malt	1	1.0 ppm	—	—	CPG 7104.07
	Malt beverages	1	0.5 ppm	—	—	CPG 7101.07
Paralytic shellfish toxin	—	—	—	—	—	—
Polbrominated Biphenyls (PBB's)	Animal feed	1	0.05 ppm	—	—	A review of Congressman W. M. Brodhead's petition to reduce FDA action levels for PBB's in food July 27, 1977.

(Continued)

Table C7 (Concluded)

Substance	Commodity	Data Source	Action Level	Type of Limit	Step	Reference
Polychlorinated Biphenyls (PCB's)	Paper food-packaging material intended for or used with human food, finished animal feed, and components intended for animal feeds	1	0.10 ppm	--	--	21 CFR 109.30 (a) (9) and 509.30 (a) (9) tolerance used stayed on 8-24-73 (38 FR 22794) 21 CFR 109.6 (d) and 509.6 (d)
Tin	Canned fruit cocktail	3	250 mg/kg	--	--	CAC/RS 78-1974
	Canned mature processed peas	3	250 mg/kg	--	--	CAC/RS 81-1976
	Canned tropical fruit salad	3	250 mg/kg	--	--	CAC/RS 99-1978
	Non-pulpy black currant nectar	3	150 mg/kg	--	--	CAC/RS 101-1978
Toxaphene	Animal feed, processed	1	0.5 ppm	--	--	CPG 7126.27-I
	Vegetables	1	1.0 ppm	--	--	CPG 7120.23-L
	Fruits	1	1.0 ppm	--	--	CPG 7120.23-L
Zinc	Non-pulpy black currant nectar	3	5 mg/kg	--	--	CAC/RS 101-1978

(Sheet 5 of 5)

Table C8

Additional Action Levels for Contaminants in Foodstuffs Used by Other Countries

Source	Contaminant	Commodity	Content, mg/kg	References
Britain	Pb	All foods	1.0 (fresh wt)	M.A.F.F., 1972
World Health Organization (WHO)	Pb	Root vegetables	0.1 (fresh wt)	WHO, 1972
		Cereal	0.1 (fresh wt)	
		Leafy vegetables	1.2 (fresh wt)	
	Cd	Root vegetables	0.05 (fresh wt)	WHO, 1972
		Leafy vegetables	0.1 (fresh wt)	
		Potatoes, cereal	0.1 (fresh wt)	
Dutch	Cu	Animal feed	20.0 (dry wt)	DMAFCMN, 1973
Dutch (unofficial)	Cd	Single animal feed	0.5 (dry wt)	European Community, 1974
		Mixed animal feed	1.0 (dry wt)	
		Roughage	1-2 (fresh wt)	
European Economic Community	Pb	Single animal feed	10.0 (dry wt)	Van Driel et al., 1982
		Mixed animal feed	5.0 (dry wt)	
		Roughage	40.0 (fresh wt)	
FDA (as of Sep 82)	Hg	Wheat seed	1.0 (dry wt)	FDA, 1982
	PBB	Animal feed	0.5 (dry wt)	
	Various pesticides	Vegetables, grains, and feeds	0.03-0.1	

Table C9

Background Levels and Allowable Applications of Several Heavy Metals for US Cropland Soils (from Holnigren et al. 1985 and Table C6)

Metal	Concentration in Surface Soils (mg/kg) 5 percentile	median	95 percentile	No Effect Allowed Addition* kg/ha	Median + Allowed Application mg/kg
Pb	4.0	11	27	1,000	511
Zn	7.3	54	129	500	304
Cu	3.7	19	96	250	144
Ni	3.8	19	59	125	82
Cd	0.035	0.20	0.78	5	2.7
pH	4.6	6.1	8.1	--	--

* Allowed application is mixed into the 0-15 cm (0-6 in.) surface layer of soil.

Table C10

Recommended or Regulated Limitations on Potentially Toxic Constituents in Surface (0-15 cm) Soils

Basis for Limitation	Contaminant	Soil Concentration	Reference
Soil Ingestion	Pb	500 mg/kg	EPA, 1977
	Hg	5 mg/kg	
	PCBs etc.	2.0 mg/kg	Fries, 1982
Plant Uptake	Cd	2.5 mg/kg (pH 5.5)	EPA, 1979
Phytotoxicity	Zn	250 mg/kg	Logan and Chaney, 1983
	Cu	125 mg/kg	
	Ni	62 mg/kg	
	Co	62	
Leaching	Cr (VI)	0.05 mg/ℓ	EPA Drinking Water Standard Table C4

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NOTES: Alphanumeric identification of pages, paragraphs, and figures was used in the appendices to distinguish them from the simple numbers used as identification of main-text paragraphs, figures and tables. Thus references to simple numbers in the appendices refer to similarly numbered items in the main text.

Mixing zone procedures given in paragraphs D1-D36 were taken from Environmental Effects Laboratory (1976).

All references cited in this appendix are included in the list of references that follows the main text.

APPENDIX D: PROCEDURES FOR AND EXAMPLES OF MIXING ZONE PROCEDURES

Volume of Dilution Water

D1. A mixing zone is that volume of water at a disposal site required to dilute contaminant concentrations associated with a discharge of dredged material to an acceptable level. In order to calculate the volume of disposal site water required for a specific proposed discharge, it is first necessary to perform the elutriate test described on paragraph 31 of the main text to determine the concentration of the critical constituents of greatest concern in the standard elutriate and in disposal site water.

D2. The next step in determining the volume of the mixing zone is the derivation of an expression for the volume of disposal site water required to dilute to an acceptable level the concentration of a critical constituent in one unit volume of standard elutriate resulting in a dilution factor D. Since the mass of the constituent of interest in one volume of standard elutriate is (1) (Ce), the mass of the constituent in D volumes of disposal site water is (D)(Ca), and the total volume is (D + 1), the resultant concentration can be determined. However, if rather than solving for the resultant concentration, one prescribes its values such that a desired water-quality standard is satisfied, then the expression below can be solved for the volume of disposal site water necessary to achieve such a dilution.

$$D = \frac{C_e - C_s}{C_s - C_a} \qquad \text{(D1)}$$

where

D = dilution factor required to dilute concentration of constituent of interest to a concentration equal to the numerical standard C_s, vol/vol

C_e = concentration of constituent of interest in standard elutriate, mg/ℓ

C_a = concentration of constituent of interest in disposal site water, mg/ℓ

C_s = numerical standard for constituent of interest, mg/ℓ

D3. The total volume of water necessary to dilute a discharge of dredged material to acceptable levels is equal to the volume calculated in equation D1 times the total volume of dredged material. This can be expressed as:

$$M = D\ V_d \qquad (D2)$$

where

M = required volume of disposal site water, cu yd

D = dilution factor required to dilute concentration of constituent of interest to a concentration equal to the numerical standard C_s, vol/vol

V_d = volume of dredged material, cu yd

D4. When using this approach to calculate the necessary volume of dilution water, the following recommendations and specifications should be considered:

a. Acute toxicity criteria rather than chronic toxicity criteria should be used in equation D1 to calculate the mixing volume. The justification for this recommendation is that dredged material disposal is an intermittent short-term event and perturbations resulting from disposal activities would not be expected to persist for the lifetime of an organism. Thus, the use of chronic toxicity criteria, based on long-term exposure, would be technically inappropriate.

b. In using standards to calculate the volume of a mixing zone, consideration should be given to the basis of the standards. For example, the most stringent standards for iron and manganese are based on aesthetic considerations. Section 230.5(b)(1) of the Register gives consideration to discharging near municipal water intakes; therefore, iron and manganese standards that are used should reflect the toxicological and other properties of these metals rather than aesthetic properties if these metals are deemed critical constituents.

c. If the elutriate test concentration C_e is less than or equal to the numerical standard C_s, no calculation is necessary since no dilution is necessary.

d. If the elutriate test concentration C_e is greater than the numerical standard C_s and the proposed disposal site water concentration C_a is less than the numerical standard C_s, the required dilution volume can be calculated as described above.

e. If the elutriate test concentration C_e is greater than the proposed disposal site water concentration C_a and the proposed disposal site water concentration C_a is greater than or equal to the numerical standard C_s, the standard cannot be achieved by dilution. Some other procedure will have to be used to evaluate the proposed discharge activity. One possible method would be to use appropriate bioassays (Appendix A).

Shape of Mixing Zone

D5. After calculating the required volume M of disposal site water that would be necessary for diluting the proposed discharge, the next step in implementing the mixing zone concept is to characterize the shape associated with the dilution volume. This can be accomplished by defining relatively simple three-dimensional geometric shapes for use with specified types of discharges and discharge conditions.

Discrete discharges

D6. The general shape with greatest apparent applicability to discrete discharge operations is that of a conical frustum whose volume M is defined by:

$$M = \frac{d}{3}\left(A_b + \sqrt{A_b A_t} + A_t\right) \qquad \text{(D3)}$$

where

d = height of frustum

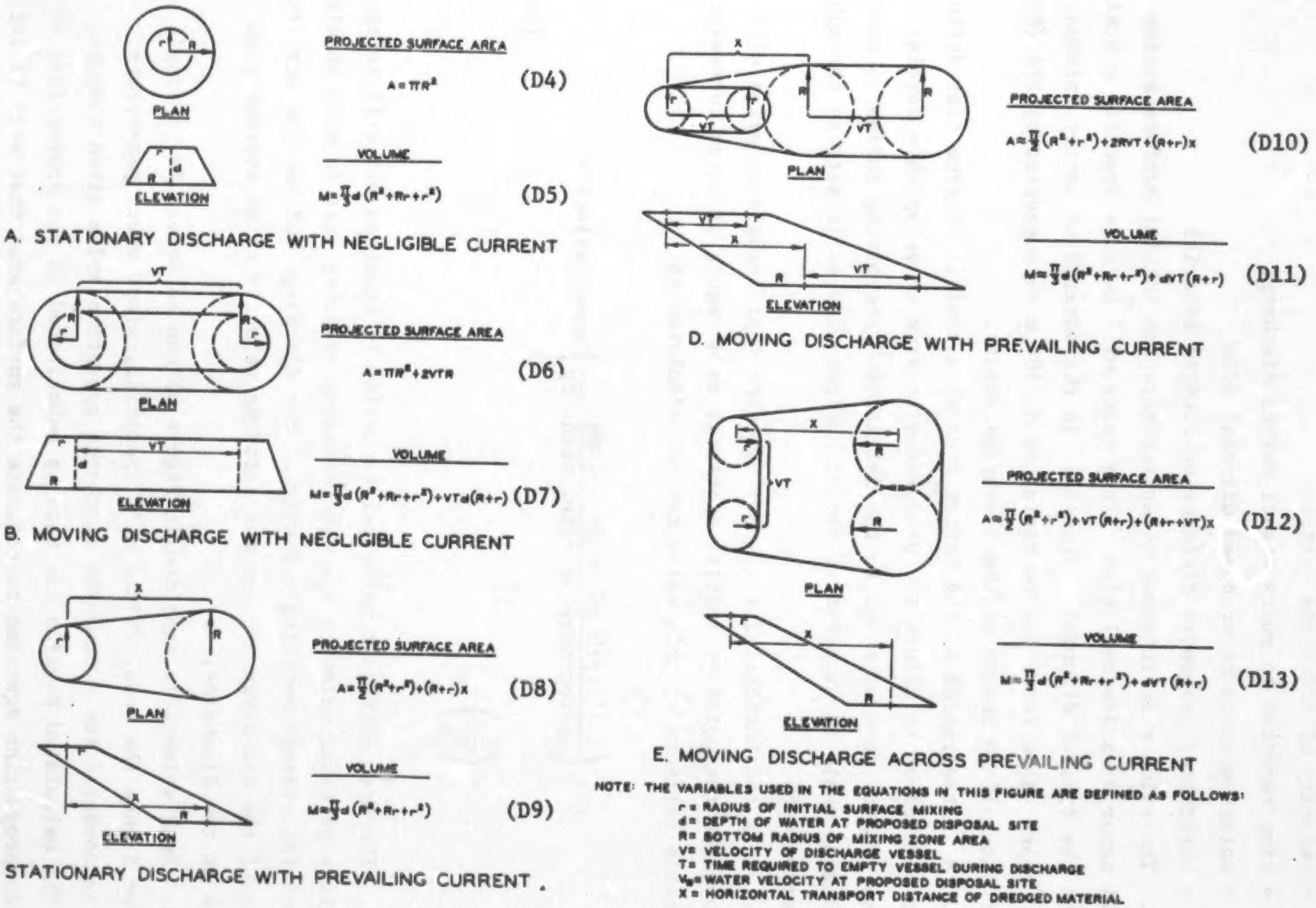
A_b = area of lower base of frustum

A_t = area of upper base of frustum

D7. Five different combinations of disposal operations and ambient current conditions are considered for discrete discharge operations (Figure D1). Each combination can be described by a volumetric and a surface area equation that will define the mixing zone for a proposed discharge operation. The variables used in equations D4-13 in Figure D1 are defined as follows:

r = radius of initial surface mixing

d = depth of water at proposed disposal site


PROJECTED SURFACE AREA
$A=\pi R^2$ (D4)
VOLUME
$M=\frac{\pi}{3}d(R^2+Rr+r^2)$ (D5)
PLAN
ELEVATION
r
R
d
A. STATIONARY DISCHARGE WITH NEGLIGIBLE CURRENT
PROJECTED SURFACE AREA
$A=\pi R^2+2VTR$ (D6)
VOLUME
$M=\frac{\pi}{3}d(R^2+Rr+r^2)+VTd(R+r)$ (D7)
VT
PLAN
ELEVATION
B. MOVING DISCHARGE WITH NEGLIGIBLE CURRENT
PROJECTED SURFACE AREA
$A=\frac{\pi}{2}(R^2+r^2)+(R+r)X$ (D8)
VOLUME
$M=\frac{\pi}{3}d(R^2+Rr+r^2)$ (D9)
X
PLAN
ELEVATION
C. STATIONARY DISCHARGE WITH PREVAILING CURRENT .
PROJECTED SURFACE AREA
$A=\frac{\pi}{2}(R^2+r^2)+2RVT+(R+r)X$ (D10)
VOLUME
$M=\frac{\pi}{3}d(R^2+Rr+r^2)+dVT(R+r)$ (D11)
X
VT
PLAN
ELEVATION
D. MOVING DISCHARGE WITH PREVAILING CURRENT
PROJECTED SURFACE AREA
$A=\frac{\pi}{2}(R^2+r^2)+VT(R+r)+(R+r+VT)X$ (D12)
VOLUME
$M=\frac{\pi}{3}d(R^2+Rr+r^2)+dVT(R+r)$ (D13)
X
VT
PLAN
ELEVATION
E. MOVING DISCHARGE ACROSS PREVAILING CURRENT

NOTE: THE VARIABLES USED IN THE EQUATIONS IN THIS FIGURE ARE DEFINED AS FOLLOWS:

r = RADIUS OF INITIAL SURFACE MIXING
d = DEPTH OF WATER AT PROPOSED DISPOSAL SITE
R = BOTTOM RADIUS OF MIXING ZONE AREA
V = VELOCITY OF DISCHARGE VESSEL
T = TIME REQUIRED TO EMPTY VESSEL DURING DISCHARGE
V_s = WATER VELOCITY AT PROPOSED DISPOSAL SITE
X = HORIZONTAL TRANSPORT DISTANCE OF DREDGED MATERIAL

Figure D1. Project surface area and volume equations for discrete discharge operations

R = bottom radius of mixing zone area

V = velocity of discharge vessel

T = time required to empty vessel during discharge

V_w = water velocity at proposed disposal site

X = horizontal transport distance of dredged material

D8. The value r is intended to approximate the initial surface mixing that will occur at a disposal site. This value will be site specific and will vary with the type of disposal operation. In the absence of better information, an upper value for r can be estimated as 100 m as suggested by EPA (EPA 1973) or one-half in length of the discharge vessel.

D9. R is the radius of the bottom area of a conical frustum that defines a volume sufficient to dilute the proposed discharge to acceptable levels. R should be greater than or equal to the initial surface mixing radius r, since the discharge would be expected to expand horizontally as it settles through the water column.

D10. X is the horizontal transport distance that dredged material will move away from the point of initial discharge as a result of water currents. A reasonable estimate of this value can be calculated as:

$$X = \left(\frac{\text{depth of water column}}{\text{appropriate settling velocity}}\right) \text{water velocity}$$

$$= \left(\frac{d}{V_s}\right) V_w \qquad \text{(D14)}$$

D11. The most difficult parameter to define in equation D14 will be the appropriate settling velocity V_s. The settling velocity that is used should represent the average settling velocity of the discharge and not the settling velocity of the discharge and not the settling velocity of an average size particle in the discharge.

D12. Each volumetric equation in Figure D1 can be solved for a single parameter R once the total volume M is specified, since other parameters should be constant for a proposed discharge operation and a given disposal site. The calculated R-value can then be substituted in the appropriate surface area projection equation to estimate the surface area that will be influenced by the proposed discharge.

D13. The area calculation allows one to determine whether the projected surface area for a proposed discharge fits within the geographical limits of the authorized disposal site (where such limits are established) and to determine the most appropriate locations for the initial dump to ensure that the projected surface area remains within the authorized disposal site. An estimate of the surface area to be influenced by a proposed discharge will also allow one to locate the disposal site in such a manner that possible adverse effects on other beneficial uses such as public water intakes or shell fisheries are avoided or minimized.

Continuous pipeline discharges

D14. The approach to be taken in calculating the necessary mixing zone for a proposed pipeline disposal operation is similar to the discrete discharge approach except that the volume of water required for dilution is expressed as a rate of flow.

$$D = \frac{C_e - C_s}{C_s - C_a} \qquad \text{(D1)}$$

with all terms as defined earlier in paragraph D2. However, since the discharge from a pipeline will occur at a specified rate V_p, the volume of ambient site water per unit time that would be required to dilute the discharge to acceptable levels can be defined as:

$$V_A = V_p D = V_p \left(\frac{C_e - C_s}{C_s - C_a} \right) \qquad \text{(D15)}$$

where

V_a = volume of site water/unit time required for dilution, cfs

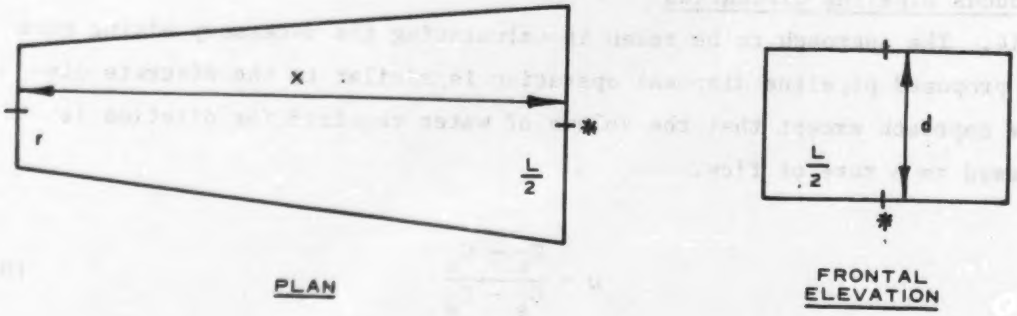
V_p = rate of disposal from pipeline, cfs

C_e = elutriate test concentration, mg/ℓ

C_a = disposal site concentration, mg/ℓ

C_s = acceptable level to be achieved by dilution, mg/ℓ

D15. It is assumed that the mixing zone associated with a pipeline discharge will resemble the shape in Figure D2. Therefore, once the required volume per unit time has been calculated, the next step is to determine the


x
r
$\frac{L}{2}$
PLAN
d
$\frac{L}{2}$
FRONTAL ELEVATION

PROJECTED SURFACE AREA

$$A = \left(\frac{L}{2} + r\right) x \qquad \text{(D16)}$$

VOLUME PER UNIT TIME

$$V_A = LdV_w \qquad \text{(D17)}$$

Figure D2. Projected surface area and volume equations for continuous pipeline discharge with prevailing current

dimensions of the mixing zone. The required volume per unit time can also be expressed as:

$$V_A = L\ d\ V_w \tag{D18}$$

where

V_A = required volume of water per unit time, cfs
L = width of mixing zone at time t, ft
d = depth, ft
V_w = velocity of water at disposal site, ft/sec

D16. Since the depth and water velocity are known or can be measured, the width of the front edge of the mixing zone can be calculated as:

$$L = \frac{V_A}{d\ V_w} \tag{D19}$$

D17. Based on information presented by Brooks (1960), the time required for the front edge of the mixing zone to spread laterally to the required width L can be computed from:

$$t = \frac{1}{\lambda}\left[0.094\ L^{2/3} - 0.149(r^{2/3})\right] \qquad \text{(D20*)}$$

where

t = required time for lateral spreading, sec
L = necessary width of the front edge of mixing zone, ft
r = one-half initial width of the plume at point of discharge (radius of initial surface mixing), ft
λ = turbulent dissipation parameter

Values for λ range from 0.00015 to 0.005 with a value of 0.005 being appropriate in a dynamic environment such as an estuary (Bradsma and Divoky 1976). As discussed earlier, values for r will be influenced by the method of disposal and will be site specific.

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* B. Johnson and M. B. Boyd. 1975. "Mixing Zone Estimate for Interior Guidance," Unpublished Memo, Mathematical Hydraulics Division, Hydraulics Laboratory, US Army Engineer Waterways Experiment Station, CE, Vicksburg, Mississippi.

D18. The calculated time can then be used to determine the longitudinal distance the discharge will travel as it is spreading to the required width. This distance can be computed from:

$$X = V_w t \qquad \text{(D21)}$$

where

X = longitudinal movement of discharge, ft
V_w = velocity of water at disposal site, ft/sec
t = necessary time of travel, sec

D19. The results of Equations D20 and D21 can then be combined to estimate the projected surface area of the proposed discharge. This area can be computed as:

$$A = \frac{L + 2r}{2} X \qquad \text{(D22)}$$

where

A = surface area, ft^2
L = width of front edge of mixing zone, ft
r = radius of initial surface mixing, ft
X = length of the mixing zone, ft

D20. This approach will characterize a proposed discharge by defining the volume of dilution water per unit time that will be required to achieve some acceptable concentration at the edge of the mixing zone. Also, the length and width (and hence the surface area) of the necessary mixing zone will be approximated.

D21. The approach used to calculate the required mixing zone for a continuous pipeline disposal operation may also be used to calculate the required mixing zone for a return flow from a confined disposal area. The calculations would be the same except that the volume of flow from a confined disposal area would be substituted for the volume of flow from a pipeline. The method should only be applied, however, where there is a discrete discharge sources such as a conduit or a weir.

Sample Computations

D22. The following computations are presented to illustrate the mixing zone concept as applied to two particular disposal operations: a moving discrete discharge in the direction of a prevailing current (Figure D1, Case D) and a continuous discharge from a pipeline (Figure D2).

Discrete discharge

D23. The following input values were used in the sample computations:

Volume of dredged material V_d = 4000 yd^3
Turbulent dissipation parameter λ = 0.005
Water column depth d = 50 ft
Vessel speed V = 6 ft/sec
Ambient water velocity V_A = 2 ft/sec
Time to end of discharge T = 360 sec
Radius of initial surface mixing r = 25 ft
Concentration of constituent of interest in standard elutriate C_e = 30 mg/ℓ
Ambient concentration C_a = 0.1 mg/ℓ
Acceptable concentration C_s = 0.5 mg/ℓ
Settling velocity V_s = 10 ft/sec

D24. The dilution factor required to dilute concentration of interest to a concentration of equal volume C_s, vol/vol, would be:

$$D = \frac{C_e - C_s}{C_s - C_a} = \frac{(30 - 0.5)}{(0.5 - 0.1)} = 73.75 \qquad \text{(D1)}$$

D25. The volume of water to dilute the discharge to acceptable levels would be:

$$M = D V_d = (73.75)(4000\ yd^3) = 2.95 \times 10^5\ yd^3$$
$$= 7.96 \times 10^6 \text{ cu ft} \qquad \text{(D2)}$$

D26. From Figure D1 (Case D), the equation for the volume of the mixing zone for a discrete discharge in the direction of a prevailing current is:

$$M = \frac{\pi}{3} d \left(R^2 + Rr + r^2\right) + d\,V\,T\,(R + r) \qquad \text{(D11)}$$

By setting the volume equal to 7.96×10^6 cu ft, this equation can be solved for R, which equals 47 ft. This value can be used with the area equation in Figure D1 (Case D):

$$A = \frac{\pi}{2}\left(R^2 + r^2\right) + 2\,RVT + (R + r)\,X \qquad \text{(D10)}$$

where X is solved by Equation D14:

$$X = \frac{\text{depth of water column}}{\text{settling velocity}}\ (\text{water velocity})$$

$$= \frac{50\ \text{ft}}{10\ \text{ft/sec}}\ (2\ \text{ft/sec}) = 10\ \text{ft}$$

to arrive at the projected surface area = 208,212 sq ft.

D27. Thus, the proposed mixing zone would have the following dimensions:

Volume = 7.96×10^6 cu ft
Projected surface area = 208,212 sq ft
Maximum dimensions = 2242 ft by 94 ft

This information would be used in considering the compatibility of the size of the mixing zone required for the proposed discharge with the size of the proposed discharge site.

Continuous pipeline discharge

D28. The following input values were used in the sample computations:

Volume of dredged material discharged per unit time V_p = 44 cu ft/sec*
Turbulent dissipation parameter λ = 0.005
Water column depth d = 10 ft
Water velocity V_w = 0.5 ft/sec
Initial width of plume 2r = 30 ft
Ambient concentration C_a = 0.1 mg/ℓ

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* Based on pipe radius of 12 in. and discharge velocity of 14 ft/sec.

Elutriate test concentration C_e = 30 mg/ℓ

Acceptable concentration C_s = 0.5 mg/ℓ

D29. The required volume per unit time will be:

$$V_A = V_P D = 44 \left(\frac{30 - 0.5}{0.5 - 0.1} \right) = 3245 \text{ cu ft/sec} \qquad \text{(D15)}$$

D30. The required width of the mixing zone will be:

$$L = \frac{V_A}{d\,V_w} = \frac{3245}{(10)\,(0.5)} = 649 \text{ ft} \qquad \text{(D19)}$$

D31. The time required to achieve the lateral spread L will be:

$$t = \frac{1}{0.005}\left[(0.094)(649)^{2/3} - (0.149)(15)^{2/3}\right] \qquad \text{(D20)}$$

$$= 1228 \text{ sec}$$

D32. The length of the mixing zone will be:

$$X = (0.5 \text{ ft/sec})(1228 \text{ sec}) = 614 \text{ ft} \qquad \text{(D21)}$$

D33. Thus the proposed mixing zone would have dimensions of:

$$\text{Surface area} = \left(\frac{30 + 649}{2} \right) 614 = 208{,}453 \text{ sq ft}$$

Maximum dimensions = 614 ft by 649 ft

This information would be used in considering the compatibility of the size of the mixing zone required for the proposed discharge with the proposed discharge site.

Evaluation of calculations

D34. The surface area and volumetric equations in Figures D1 and D2 were derived on the assumption that the dredged material would spread horizontally as it settles through the water column. Therefore, the calculated value for R should be greater than r. If the calculated value for R is less than r, this suggests that the input data is inappropriate. One possible reason for this discrepancy is that the selected value for r may have been too large. In this case, R can be recalculate using a smaller r value. (It also suggests that a cylinder with radius r and depth d will provide sufficient water for dilution and that the surface area projection of the mixing zone can be estimated with r.)

D35. Another possible reason for the calculated value of R being less than the selected value of r is the depth of the disposal site. If the depth d is large, the mixing zone will assume the shape of an inverted cone rather than a frustum. This also suggests that sufficient water is available for dilution under the surface area projection defined by r.

D36. For the conditions where d is large, it may be more appropriate to specify a maximum portion of the water column (e.g., the upper 50 ft) that can be used for a mixing zone. Then the remaining dimensions of the mixing zone can be calculated using the specified value rather than the actual water column depth.

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Sediment A--Aquatic Disposal

Calculation of Hypothetical Mixing Zone for PCB

ASSUMPTIONS

Discrete discharge from barge moving in direction of prevailing current (Figure D1, case D). Barge holds 2,700 cu yd and is 190 ft long

C_s = Water-quality criterion for PCB = 0.03 μg/ℓ

C_a = PCB concentration in disposal site receiving water = 0.005 μg/ℓ

C_e = PCB concentration in elutriate = 0.04 μg/ℓ

V_d = Volume of dredged material in barge = 2,700 cu yd (72,900 ft^3)

r = Radius of initial surface mixing = 95 ft

d = Depth of water at disposal site = 100 ft

V_w = Current velocity at disposal site (presumed to be uniform speed and direction from surface to bottom) = 3 ft/sec

V = Velocity of barge = 6 ft/sec

T = Time to empty barge during discharge = 60 sec

V_s = Mass descent velocity of discharge = 9 ft/sec

X = horizontal transport distances as result of currents = $(d/V_s)V_w$ = 33 ft

CALCULATIONS

Dilution factor D required to dilute PCB in discharge to criterion may be calculated as (Equation D1):

$$D = \frac{C_e - C_s}{C_s - C_a} = \frac{0.04 - 0.03}{0.03 - 0.005} = 0.40$$

Volume of mixing zone M required to dilute PCB in discharge to criterion may be calculated as (Equation D2):

$$M = DV_d = 0.40(72{,}900\ ft^3) = 29{,}160\ ft^3$$

Bottom radius of mixing plume R may be calculated as (Equation D11):

$$R = -\frac{1}{2}\left(r + \frac{3VT}{\pi}\right) + \frac{1}{2}\sqrt{-3r^2 - \frac{6VTr}{\pi} + \frac{9V^2T^2}{\pi^2} + \frac{12M}{\pi d}}$$

$$R = -47.01$$

CALCULATIONS (Continued)

This is physically impossible (paragraphs D8-D9). Since R must be greater than or equal to r, set $R = r = 95$ ft

Surface area projetcion A of mixing zone may be calculated as (Equation D10):

$$A = \frac{\pi}{2}(R^2 + r^2) + 2RVT + (R + r)X = 103{,}023\ \text{ft}^2$$

Length L of surface area projection of mixing zone of configuration of Figure D1, case D, may be calculated as:

$$L = r + X + VT + R = 583\ \text{ft}$$

Maximum width W of surface area projection of mixing zone of configuration of Figure D1, Case D, may be calculated as:

$$W = 2R = 190\ \text{ft}$$

Time required to achieve dilution T_d may be calculated as:

$$T_d = V_w L = 195\ \text{sec} = 3.25\ \text{min}$$

DESCRIPTION

The mixing zone required to dilute dissolved PCB in sediment A to the acute water-quality criterion would be as follows:

- Volume = 29,160 cu ft
- Surface area projection = 103,023 ft^2
- Length = 583 ft
- Maximum width = 190 ft
- Time to achieve dilution = 195 sec = 3.25 min

Sediment B--Upland Disposal Effluent

Calculation of Hypothetical Mixing Zone for *Crassostrea* Toxicity

ASSUMPTIONS

Disposal site filled with an 18-in. hydraulic dredge operating continuously, discharge over weir into waterway (Figure D2)

C_s = EC50 effluent concentration = 62 percent

C_a = Effluent concentration in receiving water = 0 percent

C_e = Effluent concentration in discharge = 100 percent

V_p = Rate of flow of discharge = 27 cu ft/sec

d = Depth of water at discharge site = 40 ft

V_w = Current velocity at discharge site (presumed to be uniform speed and direction from surface to bottom) = 1.5 ft/sec

r = Radius of initial surface mixing = 24 ft

λ = Turbulent dissipation parameter (paragraph D17) = 0.0005

CALCULATIONS

Dilution factor D required to dilute discharge to EC50 concentration may be calculated as (Equation D1):

$$D = \frac{C_e - C_s}{C_s - C_a} = \frac{100 - 62}{62 - 0} = 0.61$$

Mixing zone volume per unit time V_A required to dilute discharge to EC50 concentration may be calculated as (Equation D15):

$$V_A = V_p D = 13 \text{ cu ft/sec}$$

Maximum width L of mixing zone required to dilute discharge to EC50 concentration may be calculated as (Equation D19):

$$L = \frac{V_A}{dV_w} = 0.2 \text{ ft}$$

Time t required for plume to spread to maximum width may be calculated as (Equation D20):

$$t = \left[\frac{1}{\lambda}\ 0.094L^{2/3} - 0.149(r^{2/3})\right] = -2{,}420 \text{ sec}$$

CALCULATIONS (Continued)

(A negative time for spreading is physically impossible. This indicates the necessary spreading would occur essentially instantaneously.)

Length X of mixing zone required to dilute discharge to EC50 may be calculated as (Equation D21):

$$X = V_w t = -3{,}630 \text{ ft}$$

(A mixing zone of negative length is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

Surface area projection A of mixing zone of configuration of Figure D2 may be calculated as (Equation D22):

$$A = \left(\frac{L + 2r}{2}\right) X = -87{,}483 \text{ ft}^2$$

(A mixing zone of negative surface area is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

DESCRIPTION

The mixing zone required to dilute the effluent of sediment B to the 48-hr EC50 for *Crassostrea* larvae would be as follows:

- Flow rate of dilution water required = 13 cu ft/sec
- Surface area projection = negligibly small
- Length = neglibigly small
- Maximum width = 0.2 ft

Sediment B--Upland Disposal Surface Runoff

Calculation of Hypothetical Mixing Zone for PCB

ASSUMPTIONS

Disposal site of 60 acres, runoff from 2-in. rainfall in 1 hr flowing through weir and discharge pipe into a waterway (Figure D2)

C_s = Water-quality criterion for PCB = 0.03 μg/ℓ

C_a = PCB concentration in receiving water = 0.01 μg/ℓ

C_e = PCB concentration in effluent = 0.50 μg/ℓ

V_p = Rate of flow of discharge = 121 cu ft/sec

d = Depth of water at discharge site = 40 ft

V_w = Current velocity at discharge site (presumed to be uniform speed and direction from surfact to bottom) = 1.5 ft/sec

r = Radius of initial surface mixing = 24 ft

λ = Turbulent dissipation parameter (paragraph D16) = 0.0005

CALCULATIONS

Dilution factor D required to dilute PCB in runoff to criterion may be calculated as (Equation D1):

$$D = \frac{C_e - C_s}{C_s - C_a} = 23.50$$

Mixing zone volume per unit time V_A required to dilute PCB in runoff to criterion may be calculated as (Equation D15):

$$V_A = V_p D = 2,844 \text{ cu ft/sec}$$

Maximum width L of the mixing zone required to dilute PCB in runoff to criterion may be calculated as (Equation D19):

$$L = \frac{V_A}{dV_w} = 47 \text{ ft}$$

Time t required for mixing zone to spread to maximum width may be calculated as (Equation D20):

$$t = \frac{1}{\lambda}\left[0.094\ L^{2/3} - 0.149(r^{2/3})\right] = -32 \text{ sec}$$

CALCULATIONS (Continued)

(A negative time for spreading is physically impossible. This indicates the necessary spreading would occur essentially instantaneously.)

Length X of mixing zone required to dilute PCB in runoff to criterion may be calculated as (Equation D21):

$$X = V_w t = -48 \text{ ft}$$

(A mixing zone of negative length is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

Surface area projection A of mixing zone of configuration of Figure D2 may be calculated as (Equation D22):

$$A = \left(\frac{L + 2r}{2}\right) X = -2{,}280 \text{ ft}^2$$

(A mixing zone of negative surface area is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

DESCRIPTION

The mixing zone required to dilute PCB in sediment B upland disposal area surface runoff to the acute water-quality criterion would be as follows:

- Flow rate of dilution water required = 2,844 cu ft/sec
- Surface area projection = negligibly small
- Length = neglibigly small
- Maximum width = 47 ft

Sediment C--Upland Disposal Effluent

Calculation of Hypothetical Mixing Zone for PCB

ASSUMPTIONS

Disposal site filled with 18-in. hydraulic dredge operating continuously, discharge over weir into waterway (Figure D2)

C_s = Water-quality criterion for PCB = 0.03 μg/ℓ

C_a = PCB concentration in receiving water = 0.01 μg/ℓ

C_e = PCB concentration in effluent = 0.48 μg/ℓ

V_p = Rate of flow of discharge = 27 cu ft/sec

d = Depth of water at discharge site = 40 ft

V_w = Current velocity at discharge site (presumed to be uniform speed and direction from surface to bottom) = 1.5 ft/sec

r = Radius of initial surface mixing = 24 ft

λ = Turbulent dissipation parameter (paragraph D16) = 0.0005

CALCULATIONS

Dilution factor D required to dilute PCB discharge to criterion may be calculated as (Equation D1):

$$D = \frac{C_e - C_s}{C_s - C_a} = \frac{0.48 - 0.03}{0.03 - 0.01} = 22.50$$

Mixing zone volume per unit time V_A required to dilute PCB in discharge to criterion may be calculated as (Equation D15):

$$V_A = V_p D = 473 \text{ cu ft/sec}$$

Maximum width L of the mixing zone required to dilute PCB in discharge to criterion may be calculated as (Equation D19):

$$L = \frac{V_A}{dV_w} = 8 \text{ ft}$$

Time t required for plume to spread to maximum width may be calculated as (Equation D20):

$$t = \frac{1}{\lambda}\left[0.094\ L^{2/3} - 0.149(r^{2/3})\right] = -1{,}728 \text{ sec}$$

CALCULATIONS (Continued)

(A negative time for spreading is physically impossible. This indicates the necessary spreading would occur essentially instantaneously.)

Length X of mixing zone required to dilute PCB in discharge to criterion may be calculated as (Equation D21):

$$X = V_w t = -2{,}592 \text{ ft}$$

(A mixing zone of negative length is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

Surface area projection A of mixing zone of configuration of Figure B2 may be calculated as (Equation D22):

$$A = \left(\frac{L + 2r}{2}\right) X = -72{,}576 \text{ ft}^2$$

(A mixing zone of negative surface area is physically impossible. This indicates the necessary mixing would occur essentially at the point of discharge.)

DESCRIPTION

The mixing zone required to dilute PCB in sediment C upland disposal effluent to the acute water-quality criterion would be as follows:

- Flow rate of dilution water required = 473 cu ft/sec
- Surface area projection = negligibly small
- Length = negligibly small
- Maximum width = 8 ft